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Johnson Space Center
Research and Technology
Annual Report 1987

NASA

National Aeronautics and
Space Administration

NASA Technical Memorandum 100 463

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February 1988

Preface

The Johnson Space Center Research and Technology Report is prepared on an annual basis to highlight the Center research and technology (R&T) activities. Its intent is to inform R&T Program Managers of significant accomplishments that promise practical and beneficial program application. The report is not inclusive of all R&T tasks but is a comprehensive summary of the Center research activities. This document is updated annually.

The JSC Annual R&T Report is compiled by the Assistant Director (Plans). The personnel listed below have written the section summaries and have coordinated the technical inputs for their respective sections of the report. Detailed questions may be directed to them or to the technical monitors listed in the Significant Task Index.

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Contents

Space Sciences and Applications
Life Sciences

Summary

I

Office of Space Sciences and Applications

Life Sciences

Summary

Introduction

The Life Sciences Program at the Johnson Space Center (JSC) is furthering efforts to assure the health, well-being, and productivity of all individuals who fly in space and is continuing to contribute to a greater understanding of life in the universe. Research and operations activities continue to develop effective ways of providing health care before, after, and during flight. JSC is developing innovative techniques which will further examine, define, and counteract the adverse human physiological responses to the microgravity environment. Efforts directed at research and technology development specifically for the Space Station (and other long-term missions) are producing valuable data, skills, and hardware to meet the challenges specific to long-term habitation in space. In addition, biotechnology research at JSC continues to generate innovative techniques which

contribute to a greater understanding of basic cell science, the development of life support systems, and the possible commercialization of space.

The Spacecraft Environment and Crew Health

The impact of the spacecraft environment on crew health has always been a major life sciences concern, a concern which is heightened by the advent of the Space Station era and the onset of long-term flight. In the Biomedical Laboratories Branch, a significant effort is underway in the areas of environmental health, toxicology, microbiology, and water quality to develop effective strategies and advanced technology to verify and thus ensure spacecraft habitability. The Space Station Environmental Health Subsystem (EHS) is being designed and developed to reduce the risk of extended

exposure to chemical, biological, and/or physical contamination which could result from complex Space Station operations, such as water reclamation, materials processing, and the use of animal subjects in laboratory experiments.

Water reclamation onboard the Space Station will impose new challenges for ensuring the quality of the water the crew consumes. A research program has been initiated in the Water Quality Group to develop methods to monitor and identify specific organics in reclaimed water systems and to set maximum contaminant levels for these compounds. The Microbiology Laboratory is currently developing the Automated Microbiology System-II (AMS-II) to provide the EHS with microbial identification and quantitation data on the spacecraft environment, particularly the air and water. The AMS-II will also provide infectious disease diagnostic support and therapy information to the Space Station Health Maintenance
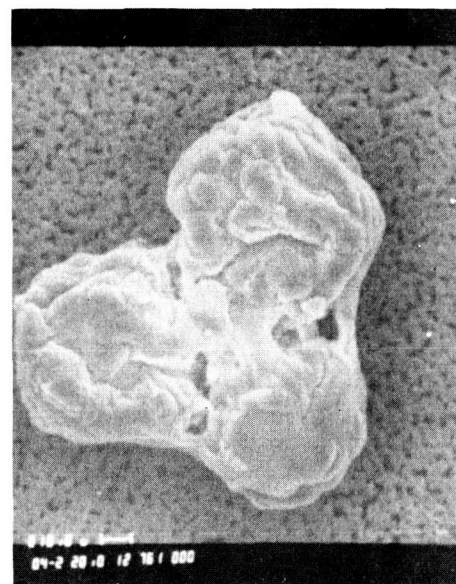
Biotechnology Program: Scanning electron microscopy, illustrating the attachment of baby hamster kidney cells to microcarrier beads and illustrating growth of the cells.
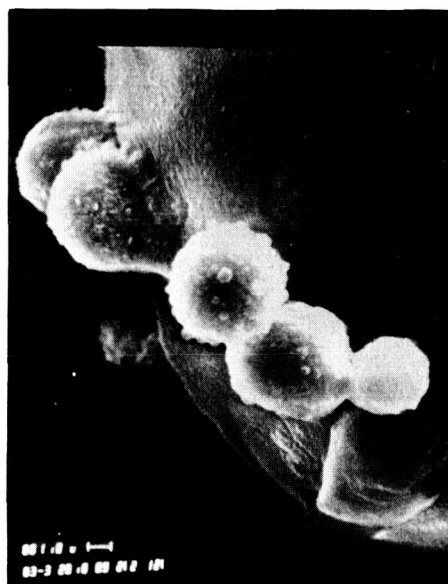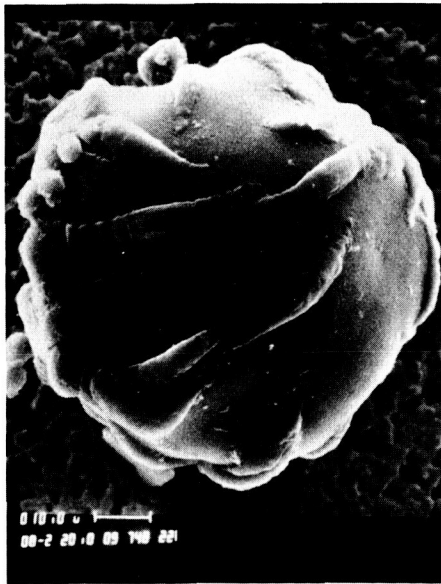
| Attachment | Growth | Superconfluence |

Facility (HMF). The Toxicology Laboratory is developing a Volatile Organic Analyzer system which will evaluate the spacecraft atmosphere on a real-time basis to ensure that the maximum allowable limits for contaminants are not exceeded.

In addition to providing onboard monitoring and analytical techniques to evaluate the spacecraft environment, it is also imperative that information be readily available on the toxicities and safe exposure levels of chemicals carried onboard the spacecraft. To address this safety issue, the Toxicology Laboratory has recently established the NASA JSC Toxicology Data Base which houses chemical information on physiochemical properties, exposure limits, toxicity, and contingency procedures.

Physiologic Responses to the Microgravity Environment

In both the Space Biomedical Research Institute (SBRI) and the Biomedical Laboratories Branch, a considerable effort is underway to develop methods to further delineate and, where needed, to counteract the physiologic responses to the microgravity environment. Researchers in the Biomedical Laboratories Branch have begun using flow cytometry and digital image analysis to investigate the expression of peptide hormone receptors on human leukocytes, providing scientists with an avenue for more detailed examination at the cellular level of endocrine-related contributions to spaceflight-induced physiologic responses. Initial efforts are also in progress to investigate the use of digital image analysis of computer tomography scans and magnetic resonance images as a possible noninvasive method for quantitative determination in humans of cerebral edema, which has been suggested as a contributing factor in the development of Space Adaptation Syndrome (SAS).

The Toxicology Laboratory is examining the hypothesis that red blood cells (RBC's) play an important role in solvent transport in the body. Study results should provide some valuable information to researchers involved in pharmacokinetic investigations and/or toxicologic risk assessments of inflight exposures to organic compounds. As part of the investigation being supported by the Biomedical Laboratories Branch to determine how the spaceflight environment affects the regulation of the RBC mass and plasma volume, a reliable and relatively simple technique was developed for intravenous injection into the tail vein of a rat using
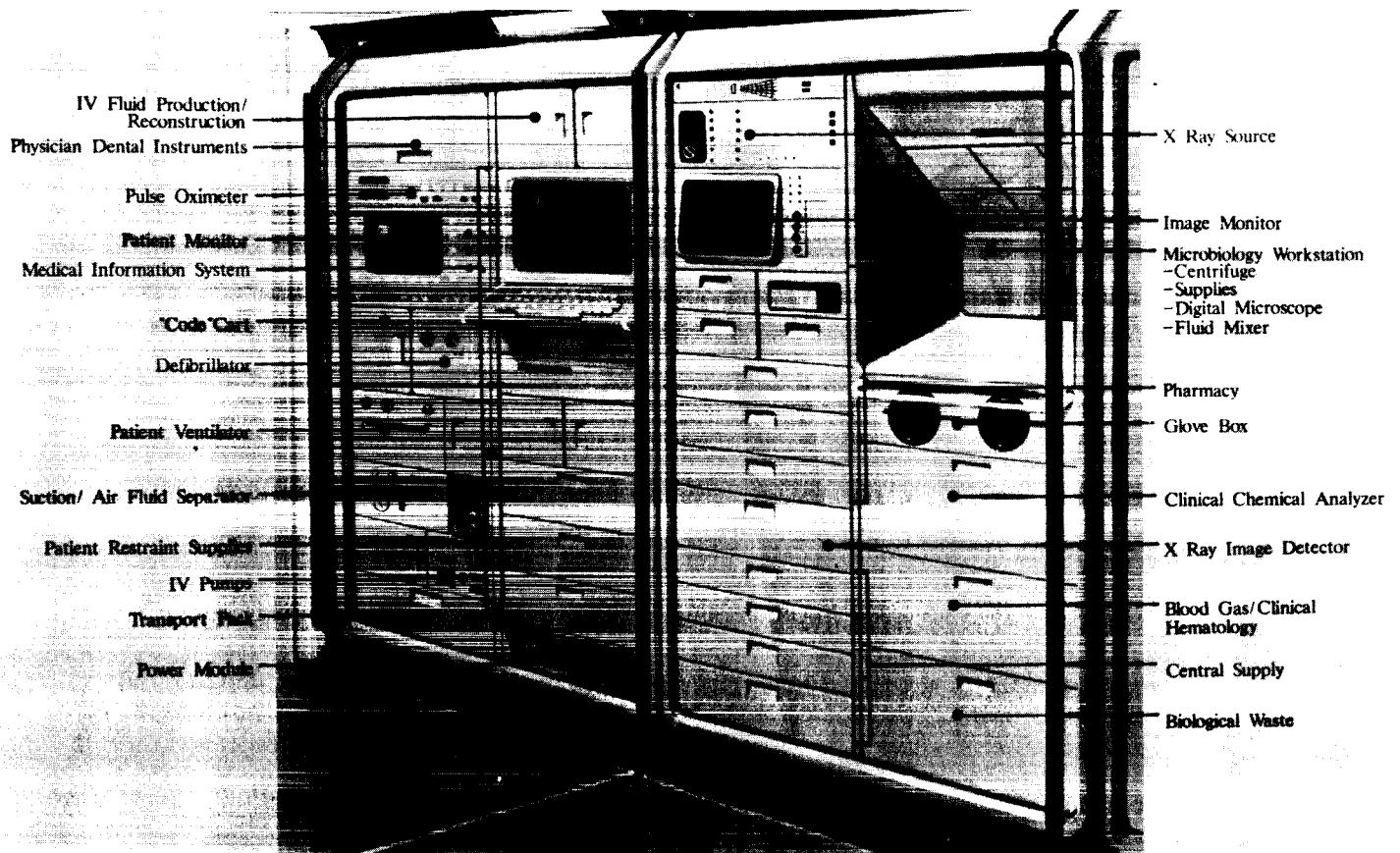

A subject being monitored with a Doppler bubble detector during altitude decompression sickness studies.

commercially available pediatric over-the-needle catheters, circumventing many of the common problems associated with repeated injections.

In the area of pharmacokinetic research, a study was recently performed to determine the applicability of inflight, noninvasive salivary drug monitoring. Data from the study confirmed the effectiveness of the monitoring technique employed and further emphasized the need for a comprehensive understanding of spaceflight-induced changes in drug dynamics. Using high performance liquid chromatography, researchers in the Biomedical Laboratories Branch have developed a sensitive quantitative assay for detecting in plasma and saliva low levels of dextroamphetamine, a drug often prescribed in combination with scopolamine to relieve the symptoms of SAS.

In the SBRI preflight adaptation trainers are being developed to reduce the incidence and severity of SAS by preparing crew-members for the unusual/novel relationships which occur between visual and other sensory input during adaptation to microgravity. As part of the research effort to reduce the risks associated with extravehicular activity (EVA), investigators utilizing the JSC hypobaric chamber to simulate EVA are using intravenous fluorescein angiography. This is a relatively noninvasive technique for directly visualizing retinal arteries and veins, in order to determine whether retinal vessels become occluded or the blood-retinal barrier is disrupted by the generation of decompression-induced venous gas emboli (VGE). Tests performed at JSC and Brooks Air Force Base to determine the oxygen prebreathe procedure providing optimum protection from EVA-induced VGE and decompression sickness have provided researchers with a "descriptive" formula for quantifying the risk involved in a given decompression event.

IV Fluid Production/
Reconstruction
Physician Dental Instruments
Pulse Oximeter
Patient Monitor
Medical Information System
Code Cart
Defibrillator
Patient Ventilator
Suction/ Air Fluid Separator
Patient Restraint Supplies
IV Pumps
Transport Pack
Power Module

X Ray Source

Image Monitor
Microbiology Workstation
−Centrifuge
−Supplies
−Digital Microscope
−Fluid Mixer

Pharmacy
Glove Box

Clinical Chemical Analyzer
X Ray Image Detector

Blood Gas/Clinical
Hematology

Central Supply
Biological Waste

The preliminary two-rack configuration of the Space Station Health Maintenance Facility.

Health Maintenance and Medical Treatment Onboard the Space Station

The Space Station HMF development group is continuing its effort to provide sophisticated capabilities for diagnosis, treatment, and monitoring of common medical problems that may occur during a long-term mission. A prototype Medical Information Bus has recently been developed to provide data integration from the various subsystem instruments into the electronic medical record contained in the HMF Medical Decision Support System. In addition, a study has just been successfully completed to determine the most effective technique for performing a key surgical procedure under microgravity conditions.

With the assistance of bioengineers at the University of Utah, a metabolic gas monitor (MGM) is being designed and built as a component of the HMF's ventilator/respiratory support system. The MGM will function as a medical and exercise monitor, measuring the flow rate of expired gas and the O_2 and CO_2 concentrations in the inspired/expired gas. As part of the ventilator system development, studies were performed to determine the impact of the

exhaust gases on the spacecraft environment, including the Crew Emercency Return Vehicle, and it was determined that the exhaust could elevate the ambient oxygen concentration above acceptable limits in the spacecraft environment. As a result, recommendations were made for the development of a closed-loop, computer-controlled gas delivery system.

Recent efforts have also been directed toward developing a radiologic imaging system capable of generating diagnostic quality images for display and interpretation on both the Space Station and the ground. To assist in accurate diagnosis and monitoring of disease states, a spaceflight-compatible clinical chemistry analyzer is currently being developed, based on Kodak's Ektachem technology. As part of the development effort on the HMF pharmacy and central supply subsystem, studies are currently being performed to evaluate the effects of microgravity and decompression on pharmaceutical packaging and storage systems. In addition, because of Space Station weight constraints, development is underway on a sterile water for injection system which will provide the ability to administer drugs and

fluids as aqueous solutions formed at bedside, using the onboard potable water supply system.

Human Factors Design and Development

The JSC Man-Systems Division is continuing to advance the skills and technology available for enhancing the quality of life in space. Current efforts include the design and development of a nonintrusive behavioral data collection system to gather specific information on crewmembers while living and working in the spaceflight environment. In planning various Space Station habitability features, Man-Systems is adding an artificial intelligence module to its computer graphics man-model TEMPUS program. In addition, engineering efforts are underway in the Anthropometry and Biomechanics Laboratory to improve the reach capabilities of the current Shuttle space suit and have resulted in the development of three versions of a proposed new high-pressure suit.

Space Sciences and Applications
Life Sciences

Significant Tasks

The Space Station Environmental Health Subsystem

PI: Dane M. Russo, Ph.D./SD4
    Duane L. Pierson, Ph.D./SD4
Reference OSSA 1

Many Space Station operations such as water reclamation, materials processing, and use of animal subjects in laboratory experiments could result in chemical, biological, and physical contamination of the Space Station internal environment. Consequently, Space Station crewmembers could be exposed to complex mixtures of air, water, and surface contaminants for relatively long periods of time. The Space Station Environmental Health Subsystem (EHS) is being developed to reduce the likelihood of such exposures and to help ensure Space Station habitability.

Major EHS functions include· environmental planning, environmental monitoring, assessments of environment-crew health relationships, and management of applicable in-flight operations. EHS flight hardware will include a central workstation within the Space Station Habitation Module and auxilary components located in other habitable areas to support environmental monitoring and sampling. The EHS includes seven subsystem components: toxicology, microbiology, vibroacoustics, radiological health, barothermal physiology, water quality, and a data management system (DMS). The DMS will be utilized for subsystem control and for acquisition, analyses, and storage of environmental data generated by the subsystem components. The EHS will interface with other Space Station systems such as the Environmental Control and Life Support (ECLSS) subsystem through the Space Station core DMS.

EHS development is synchronized with Space Station milestones and includes three major phases: Concept Definition, Concept Evaluation, and Flight Hardware Development. Phase activities are being conducted in parallel fashion rather than sequentially to keep pace with the Space Station Program schedule. Ongoing definition activities include identifying expected Space Station contaminants and their sources, establishing acceptability limits for these contaminants, and identifying environmental monitoring technologies and strategies to ensure compliance with contamination limits. Concept evaluation includes surveys of available technologies and judgment of the suitability of these technologies in light of numerous EHS constraints.

EHS constraints include limited weight and volume allowances and minimal crew time available for system operation and maintenance. These constraints will require utilization of the most advanced technologies and, in most cases, modification of commercially available equipment to achieve microgravity compatibility and the greatest amount of miniaturization practically feasible. In some cases constraints on the EHS will require development of totally new technologies rather than extensions of those currently available.

One of the key features of EHS development is the utilization of engineering and system integration considerations during the early phases of EHS definition. Early integration of medical, scientific, and engineering requirements helps focus EHS activities toward efficient and practical implementation, thus ensuring the highest quality and most cost-effective system possible.

Environmental monitoring equipment which is lightweight, which can be easily operated and maintained, and which is highly reliable and accurate could be readily employed in many different industrial and Government settings. Implementation of the EHS will require the development of equipment with these characteristics and will contribute to NASA's strong research and technology base.
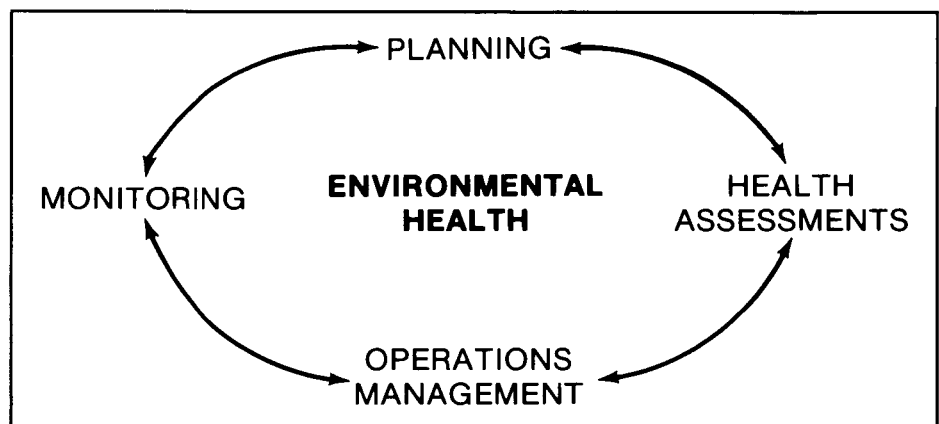
The Environmental Health Subsystem is being developed to meet Space Station environmental health needs.

Environmental Health Subsystem functions.

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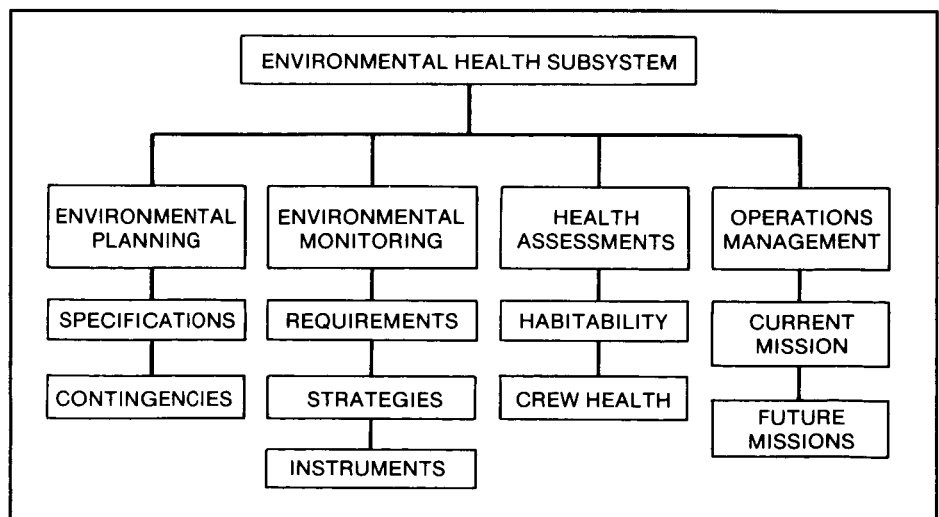
Automated Microbiology System-II for Space Station

PI: Harlan D. Brown, Ph.D./SD4
     Duane L. Pierson, Ph.D./SD4
Reference OSSA 2

The Biomedical Laboratories Branch at NASA Johnson Space Center is responsible for developing and implementing the microbiology capability for Space Station. Primary roles for this capability will be: (1) to provide infectious disease diagnostic support and therapy information to the Health Maintenance Facility and (2) to provide microbial identification and quantitation data to the Environmental Health Subsystem of the Space Station environment with particular emphasis on the microbial quality of air and reclaimed/recycled water. Investigators conducting experiments on Space Station under the auspices of the Biological Research Project may also utilize the onboard microbiology capability.

Essential requirements of the Space Station microbiology capability are to:

- Rapidly identify a wide variety of microbial isolates from many sources, e.g., clinical and environmental.
- Perform antimicrobial sensitivity testing rapidly.
- Be automated and require only minimal crew training and work.
- Provide for interpretation of data onboard and for downlinkage of both raw and interpreted data.
- Be compatible with constraints imposed by the design and operational conditions of Space Station.
- Be able to incorporate new technological advances.
- Coordinate environmental and clinical microbiology data to facilitate epidemiological investigations.

The Microbiology Laboratory in the Biomedical Laboratories Branch at NASA Johnson Space Center has worked jointly with VITEK System, McDonnell Douglas Health Systems Company to develop and test a microbiology system suitable to the needs and requirements of the Space Station program. The present collaboration represents a new phase of this company's involvement in NASA microbiology, an involvement dating back to the development of a Microbial Load Monitor in 1971.

The unit currently undergoing testing in the NASA Johnson Space Center Microbiology Laboratory, known as the Automated Microbiology System-II (AMS-II), is downsized to fit an Orbiter mid-deck locker while utilizing the existing technology found in the VITEK Jr. and the Automated Microbial System, which are used worldwide in hospitals and industry. The new AMS-II will probably find similar private sector application in small hospitals, clinics, and industry.

The technology is based on the use of credit-card-sized plastic cards manufactured with 30 test wells which contain reagents for microbe identification or antimicrobial sensitivity testing. The automated system electronically detects microbially induced chemical reactions and growth in the test wells. This data is processed by an internal computer which compiles and translates results from each test well into a microbe identification, and when required, antimicrobial sensitivity patterns. Ten isolates can be processed simultaneously with identifications of most organisms being accomplished in 2 to 4 hours. The system generates a report for immediate use and stores the data on each isolate for future reference.

The technology is highly flexible in that a wide variety of tests and research studies can be performed by the use of customized cards in which the test wells contain appropriate culture media or reagents. In this manner, developing technologies such as gene probes and monoclonal antibody studies can be readily adapted to the existing AMS-II onboard Space Station.

Ongoing development plans for the AMS-II include further laboratory-based evaluation, flight testing on the NASA KC-135 aircraft, and certification for STS flights.
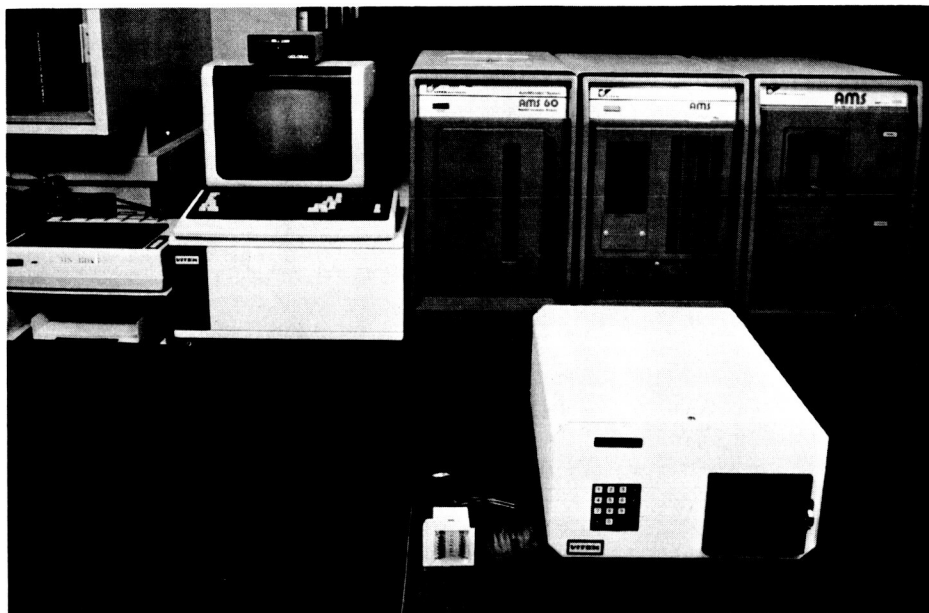
AMS-II, shown in front of a standard laboratory model AMS.

AMS-II, showing the card carousel in the reader/incubator chamber.
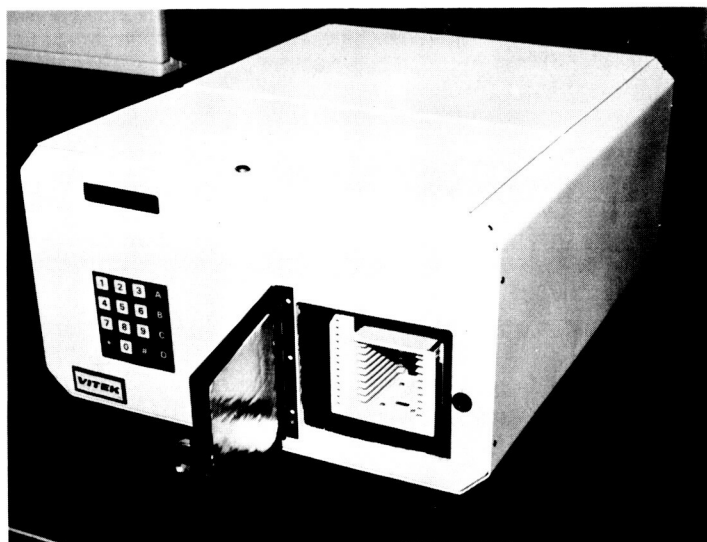
Volatile Organic Analyzer for Spacecraft Air Quality Monitoring

PI: Theodore J. Galen/SD4
     Duane L. Pierson, Ph.D./SD4
Reference OSSA 3

In manned space exploration, maintaining the quality of the spacecraft air requires that levels of potentially harmful volatile compounds present in the breathing atmosphere be evaluated on a real-time basis. A Volatile Organic Analyzer consisting of three subsystems, a gas chromatograph, a mass detector, and a computer, is being developed to monitor atmospheric contaminants. Candidate technologies for each of the three subsystems have undergone extensive evaluation and testing in the Toxicology Laboratory of the Biomedical Laboratories Branch at JSC. These tests, which were initially performed with large standard laboratory instrumentation, have lead to the development of a flight prototype system.

The goal of the current development effort is to maintain or enhance the Volatile Organic Analyzer system's analytical performance while combining the three subsystems into an integrated package. Over the past year, progress has been made in reducing the weight and volume of the laboratory versions of each of the three subsystems. The first prototype miniature gas chromatograph subsystem has been fabricated at one-sixth the volume and weight of the laboratory version. This subsystem includes a sampling pump which is used to draw an air sample into a two-step concentrator. The sample is then introduced into the fused silica capillary column for individual component separation. An ion trap detector was evaluated for the mass analyzer subsystem. Identification of the unknown compounds present in the sample occurs in the ion trap detector on the basis of the compound's unique mass spectra. A version of the flight-certified GRID computer has been tested and found compatible with the laboratory version of the computer subsystem. This subsystem is used as the overall system controller, regulating the sampling and thermal functions of the gas chromatograph and operating the ion trap detector.

To test the performance of the mass analyzer and computer subsystems, gas and liquid phase standards were prepared. The limits of detection and the overall performance of the subsystem were evaluated using these standards. The limits of detection have been improved by the new ion trap software to below 10 pg of analyte.

The usable linear range of the system has been improved to include analyte quantities from 10 pg to 10 μg. The new software has also improved compound identification by increasing the precision of comparisons of the unknown analyte spectra with the known reference mass spectra in the National Bureau of Standards data base. The miniature gas chromatograph subsystem has been integrated with the ion trap detector. The computer software has been written for control of the sample timing functions and four independent thermal zones in the gas chromatograph subsystem.

Work is currently in progress on the mechanical and electrical integration of the miniature gas chromatograph, the ion trap detector, and the computer subsystems into a single package. This process will include further significant reductions in total system weight and volume. Flight qualification of such a system will allow for a better understanding of the trace level contaminant composition and effectiveness of the air purification system within the spacecraft. In addition, the Volatile Organic Analyzer will verify that the maximum allowable limits for contaminants have not been exceeded and that the quality of the breathing air in the spacecraft is safe.

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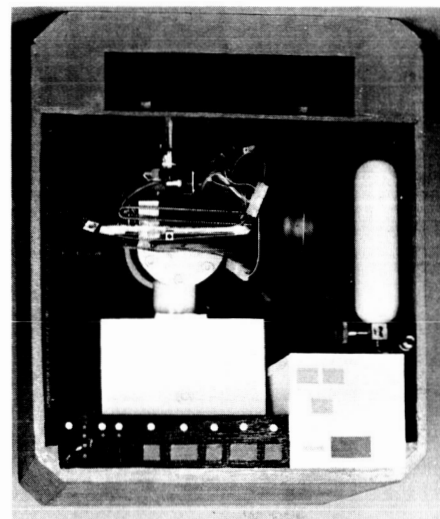
Double Shuttle locker mockup of the Volatile Organic Analyzer.

Operational prototype of the Volatile Organic Analyzer (left to right — computer, gas chromatograph, ion trap detector).
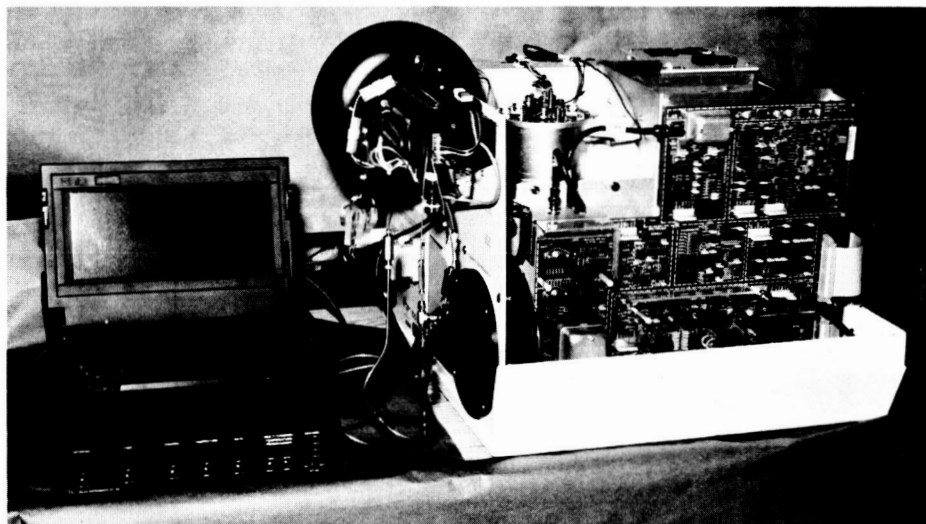
NASA JSC Toxicology Data Base

PI: Chiu-Wing Lam, Ph.D./SD4
Duane L. Pierson, Ph.D./SD4
Martin E. Coleman, Ph.D./SD4
Reference OSSA 4

Since the beginning of the space program, NASA has been concerned with the safety of the spacecraft living environment. This enclosed environment serves not only as the living quarters but also as the laboratory in which experiments are conducted. Chemical contaminants in the spacecraft atmosphere can come from such elements as mission payload materials, utility chemicals, offgassing products from spacecraft interior components, and crew metabolites. It is essential that the toxicities of these chemicals and their safety exposure levels be known. The NASA JSC Toxicology Data Base has been developed recently by the Toxicology Laboratory of the JSC Biomedical Laboratories Branch to address these safety issues.

To assess the potential hazard of payload chemicals, mission payload experiments are reviewed by the JSC Toxicology Group. Information on quantities, physical states, and appearances of the chemicals are stored into the Mission Chemical-Toxicological Reports of the NASA JSC Toxicology Data Base. Toxicology assessments are then performed on these chemicals and entered in the computer. These reports allow flight surgeons, crewmembers (if the data base is loaded into an onboard computer), toxicologists, and other users to review what chemicals will be used in a particular mission or in a particular experiment in the mission and how toxic they are. The data base will also permit users to rapidly retrieve information about the potential hazard of a chemical spill in the spacecraft.

For those specific payload chemicals which are of toxicological concern, more detailed assessments are conducted. Information on these compounds is gathered from toxicological and medical literature, especially from reports on industrial exposures and accidental poisonings. The literature is reviewed by a toxicologist, and relevant information is extracted and stored in the second section of the Toxicology Data Base, the computerized NASA JSC Toxicology Data Sheets. The data sheets consist of four major sections: (1) physiochemical properties, (2) exposure limits set by NASA and other agencies, (3) toxicities which include toxic signs and symptoms, and (4) contingency procedures. In addition to supplying information for toxicological

assessments, the data sheets provide valuable information on cleanup procedures in the event of a chemical spill and on first aid and medical treatment following exposure to toxic agents. The latter information is being developed in collaboration with the SD2 Medical Operations Branch of the Medical Sciences Division.

Toxicology information on chemicals other than those used in payload experiments is also entered in the NASA JSC Toxicology Data Base. The information includes utility chemicals, spacecraft atmospheric pollutants, rocket fuels, heat exchangers, fire extinguishants, hydraulic fluids, and crew metabolites. Subsequently, the data base can also provide toxicity information to NASA's Offgassing Testing Program so that materials that offgas toxic

levels of chemicals will not be used in the spacecraft living environment. The data base will support the Payload Safety Review Panel's recommendation for the selection of less toxic utility chemicals and for levels of containment of payload chemicals. The information in the data base has already been used to set spacecraft maximum allowable concentration (SMAC's) limits. This toxicology data base, in conjunction with onboard atmospheric monitoring and sample collecting systems, payload safety reviews, and other NASA environmental health programs, will safeguard against contamination of the living environment, maintain the health and well-being of crewmembers, and contribute to the overall success of a mission.
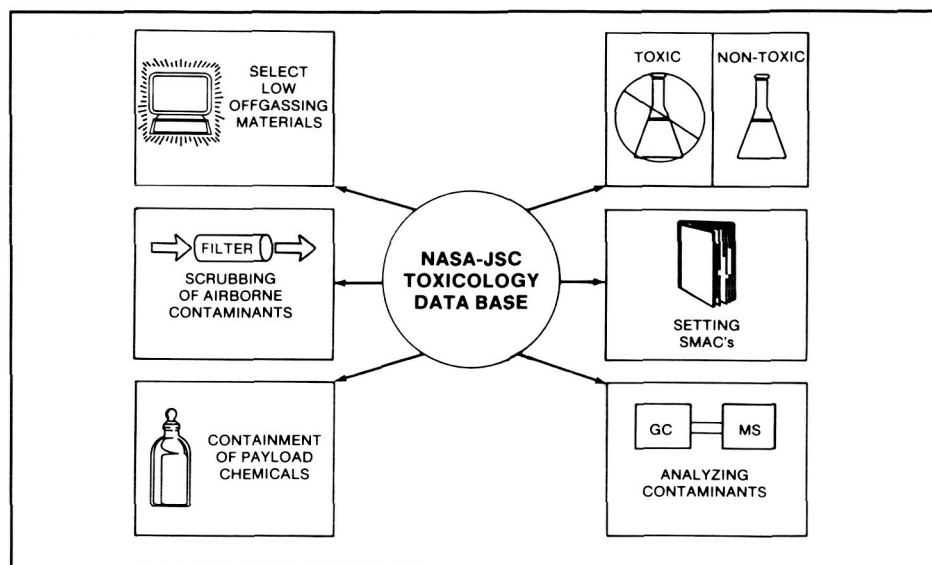
NASA JSC Toxicology Data Base.

Sources of spacecraft atmospheric contamination.
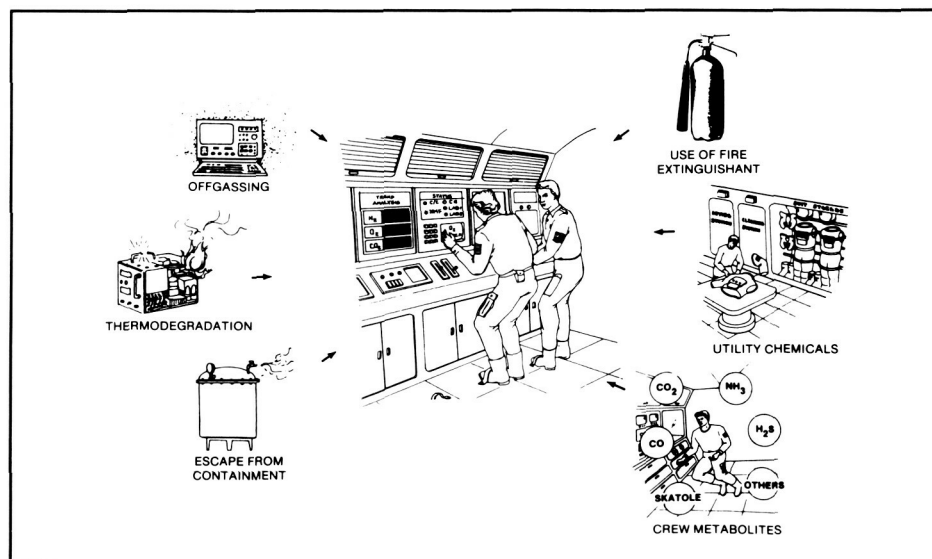
Quantitation of Cerebral Edema by Digital Image Analysis of Tomographic Imaging Scans

PI: Allan Hamilton, M.D.
    Richard Meehan, M.D.
    Clarence F. Sams, Ph.D./SD4
Reference OSSA 5

Cerebral edema and elevated intracranial pressure have been suggested as contributing factors in the development of Space Adaptation Syndrome (SAS). These factors are likely to accompany the headward fluid shift that occurs upon exposure to microgravity. They also, however, cause a variety of symptoms in individuals on Earth, such as nausea, headaches, and sensory illusions, symptoms also associated with SAS. Noninvasive methods to quantitatively determine cerebral edema in humans have not been developed with the sensitivity necessary for measurement of the mild or low-grade edema that one would expect from a microgravity-induced fluid shift. Digital image analysis of computed tomography (CT) scans and magnetic resonance images (MRI's) offers a potential method for obtaining these data.

Initial efforts in progress at the Johnson Space Center are centered around the analysis of CT scans. CT scans provide cross-sectional images of the brain which allow the differentiation of tissue and fluid within the skull. Cerebral edema is observed as a decrease in the size of the spaces containing cerebrospinal fluid (CSF) as the swelling of the brain tissue displaces the CSF from the rigid cranial vault. Initial ground-based studies have shown measurable differences in the area of the fluid-filled ventricles before and after experimentally induced mild cerebral edema. These measurements require precise and reproducible orientation of the CT scans and accurate definition of the spaces containing CSF. Software is currently being developed to define the perimeter of the cerebral ventricles and to determine their cross-sectional area. These studies are being carried out in collaboration with Dr. Allan Hamilton of the Neurosurgical Services, Massachusetts General Hospital and Harvard School of Medicine and with Dr. Richard Meehan of the University of Texas Medical Branch in Galveston.

The application of digital image analysis to the study of medically related problems will likely increase significantly in the near future. The procedures being developed during the course of this study with CT scans are readily transferable to MRI and other imaging technologies. Magnetic resonance imaging has the potential for greater resolution of the fluid and tissue boundaries and may provide more direct information concerning the degree of tissue hydration. The development of more capable software should allow the three dimensional reconstruction of the fluid spaces and comparison of total fluid volumes. These techniques will provide the general medical community with an effective method to noninvasively assess cerebral edema and provide the potential for early diagnosis of edemic complications. Further studies will be performed to explore these possibilities and to advance the use of digital image processing to life science investigations.

Digital image analysis of computer tomography scans. (a) Computed tomography scan of a horizontal section through the brain of a normal individual. (b) Another view of the scan in (a) with the unsmoothed outline of the ventricular spaces overlayed. Continued digital image processing allows the smoothing of edges and determination of the intraventricular area of the brain slice.

(a)

(b)
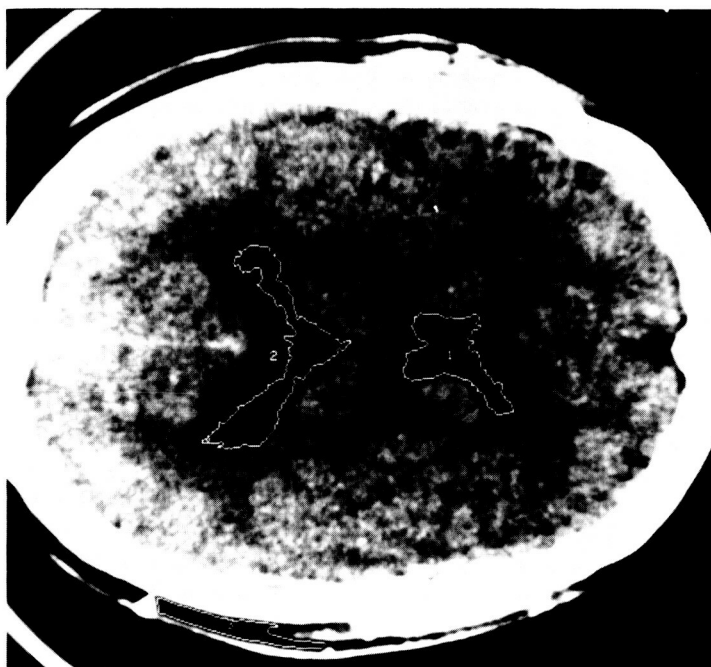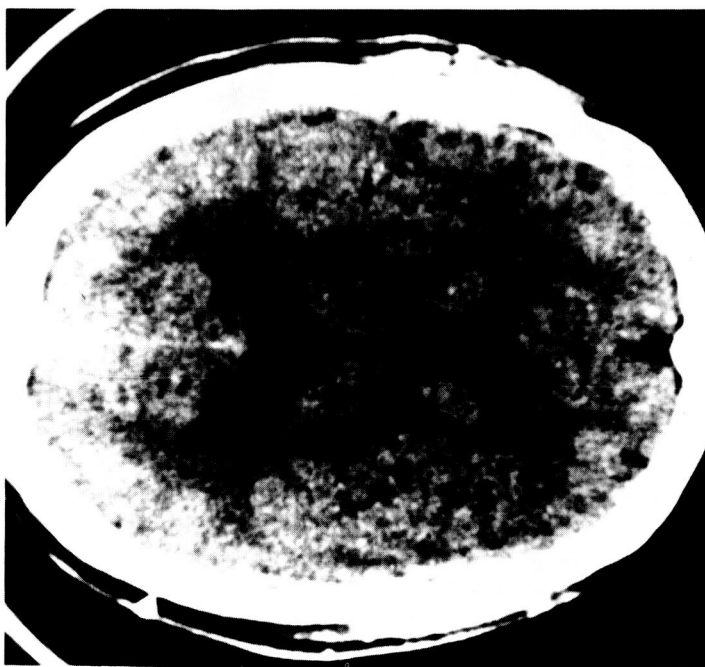
The Mechanism of Organic Solvent Transport in the Blood

PI: Chiu-Wing Lam, Ph.D./SD4
     Duane L. Pierson, Ph.D./SD
     Theodore J. Galen/SD4
Reference OSSA 6

It is well documented that long-term space-flight alters the body's homeostasis. The most noticeable physiological changes involve the hematological system, bones, and muscles. Hematological studies on crewmembers consistently show a decrease in the red blood cell (RBC) population.

Lam et al. (J. Appl. Toxicol. 6, 81-86, 1986) recently observed that RBC's play an important role in the uptake and transport of carbon disulfide (an organic solvent which has been identified in several in-flight air samples) in blood and proposed that RBC's may also play an important role in the uptake and transport of other organic compounds in the body. In-flight atmospheric samples have shown that pollutants in the Orbiter are mainly organic solvents or volatile compounds which probably offgas from the nonmetallic materials of spacecraft components. It appears that a decrease in RBC's may affect the body uptake of organic vapors by crewmembers during spaceflight. A study has been conducted in the Toxicology Laboratory of the JSC Biomedical Laboratories Branch to examine the hypothesis that RBC's play an important role in solvent transport in the body. The results from this study may help our understanding of the mechanism of organic solvent transport in the body and provide some valuable pharmacokinetic information for toxicologic risk assessments of in-flight exposures to organic compounds.

Rats were exposed by inhalation to a nominal concentration (500 p/m) of n-hexane, chloroform, toluene, methyl isobutyl ketone (MIBK), or diethyl ether. In the blood, n-hexane, chloroform, and toluene, three hydrophobic solvents, were mainly carried by the RBC's as shown in the table. MIBK and ether, the more water soluble (hydrophilic) solvents, were distributed in the plasma and RBC's approximately equally. The percentages of these solvents transported by RBC's in blood approximately parallel the hydrophobicity of these solvents. Similar results were obtained in vitro when saturated aqueous solutions of these solvents were added to rat blood. In vitro studies were also conducted on human blood. The fractions of uptake of n-hexane, chloroform, and toluene (the three hydro-phobic solvents) into the human RBC's were substantially lower than the fractions of uptake of these solvents into the rat RBC's; however, the fractions of MIBK and ether (hydrophilic solvents) found in human RBC's were similar to those found in rat RBC's. When saturated solutions of these solvents were added to plasma or RBC samples, a majority was recovered from plasma proteins or hemoglobin, respectively; a minor portion of each of the added solvents was recovered from plasma water or red cell water. Less than 10% of each of these solvents added to the RBC's was recovered from the membrane fractions.

These results indicate that RBC's play an important role in the uptake and transport of organic solvents in blood and that organic solvents in blood are mainly transported by proteins. RBC's, or specifically the hemoglobin (the red cell protein) from humans and rats, exhibit substantial difference in affinity for hydrophobic solvents. These observations further indicated that the presence of organic compounds in the RBC's and the solubility of organic compounds into proteins, which have been traditionally ignored, should not be overlooked in pharmacokinetic and toxicologic studies.

DISTRIBUTION OF SOLVENTS IN THE BLOOD OF INHALATION-EXPOSED RATS

Solvent	Plasma (μg/ml)[a]	RBC's (μg/ml)[a]	RBC's / (RBC's + Plasma)
n-Hexane	0.06	0.86	93.8%
Chloroform	9.40	79.98	89.5%
Toluene	0.98	1.65	62.7%
MIBK	11.72	12.73	52.1%
Diethyl ether	4.35	4.15	48.8%

[a]The average amount of solvent found in the plasma or RBC's of rats exposed to 500 ppm of the indicated solvent.

Salivary Drug Levels — A Tool For Pharmacokinetic Evaluations and Therapeutic Drug Monitoring in Space

PI: Nitza M. Cintron, Ph.D./SD4
      Lakshmi Putcha, Ph.D./SD4
      Yu-Ming Chen, Ph.D./SD4
Reference OSSA 7

The observation that a wide range of physiological and biochemical changes occur during spaceflight suggests that these changes alter the kinetics and dynamics of drugs administered to crewmembers during flight. While the need for elucidating such changes has been widely recognized, technical and operational constraints of multiple blood sampling required for these studies limit their implementation during spaceflight. The usefulness of salivary concentration profiles as an alternate noninvasive method for clinical monitoring of certain drugs has been established. The feasibility of such an application of saliva drug levels depends upon the distribution of detectable levels into saliva and the establishment of a consistent saliva/plasma (S/P) ratio over the entire disposition profile of the drug. In an attempt to determine the applicability of noninvasive salivary drug monitoring for pharmacokinetic and pharmacodynamic evaluation of therapeutic agents during spaceflight, three drugs that are frequently used by crewmembers have been selected for in-flight study: acetaminophen, a common pain relief medication whose disposition characteristics have been well established; scopolamine, a drug currently used for the symptomatic relief of Space Adaptation Syndrome; and dextroamphetamine, given in combination with scopolamine during missions.

Ground-based, in-house investigations to establish the S/P ratios of acetaminophen and scopolamine have been conducted in normal subjects. Following oral administration, both acetaminophen and scopolamine readily distribute into saliva with consistent S/P ratios. Pharmacokinetic evaluation and bioavailability estimations of these drugs using saliva and plasma concentration data are in good agreement. Based on these results, salivary pharmacokinetics of acetaminophen (650 mg) and scopolamine/dextroamphetamine (0.4/5 mg) during spaceflight have been evaluated, following oral administration to crewmembers before and during missions. In-flight saliva samples were collected using the saliva collection system designed and developed at JSC. Samples were analyzed by established laboratory methods for determining respective drug concentrations.

Significant changes in the concentration profiles occur during space flight. These changes are more pronounced during the absorption phase of the profile than during the elimination phase. Rate of absorption and time to reach peak saliva concentration calculated from preflight and inflight data indicate that there is a significant decrease in the absorption rate of acetaminophen during flight. There is a resultant twofold increase in the time to reach peak concentration during flight. The elimination rate of the drug, however, did not change significantly. Analysis of a limited number of samples from the ground-based and inflight study suggest that detectable changes in saliva concentration-time profiles of scopolamine occur during missions. These results support the predictions that change in drug dynamics may occur during flight as a result of the physiologic condition of crewmembers. For example, dehydration and reduction of gastrointestinal motility, both of which prevail in astronauts during missions, influence the absorption of acetaminophen. The direction and magnitude of these changes depend on a number of flight-specific variables like mission day, manifestation of space motion sickness, and the overall physiologic response to weightlessness of the participating crewmember. Such changes in the pharmacokinetics of drugs administered to crewmembers during a mission may result in ineffective therapeutic response or unexpected side effects.

The present investigation constitutes the beginning of a comprehensive pharmacokinetic characterization of drugs administered to crewmembers during space flight. Results of this study further emphasize the need for a comprehensive understanding of space-flight-induced changes in drug dynamics to identify effective methods of pharmacologic intervention for mission-induced pathophysiologic conditions.

Relationship between plasma and saliva therapeutic concentrations.
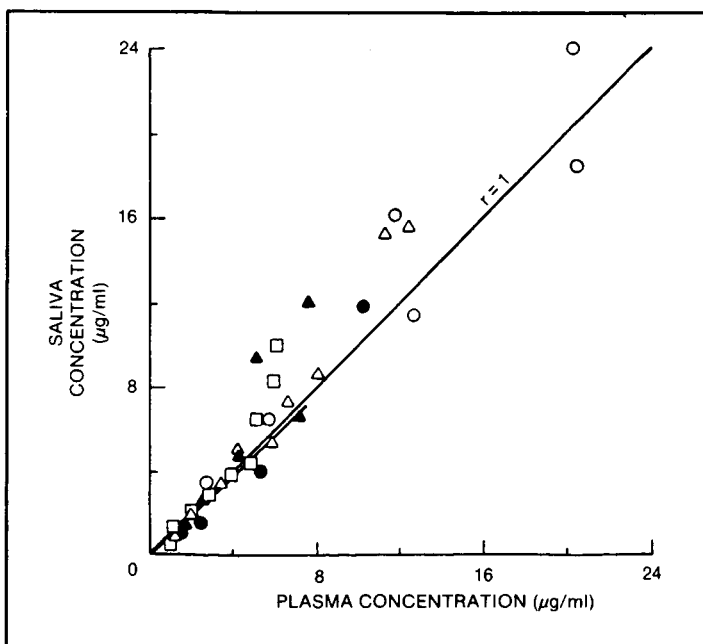
Concentration-time profiles following scopolamine intravenous administration.
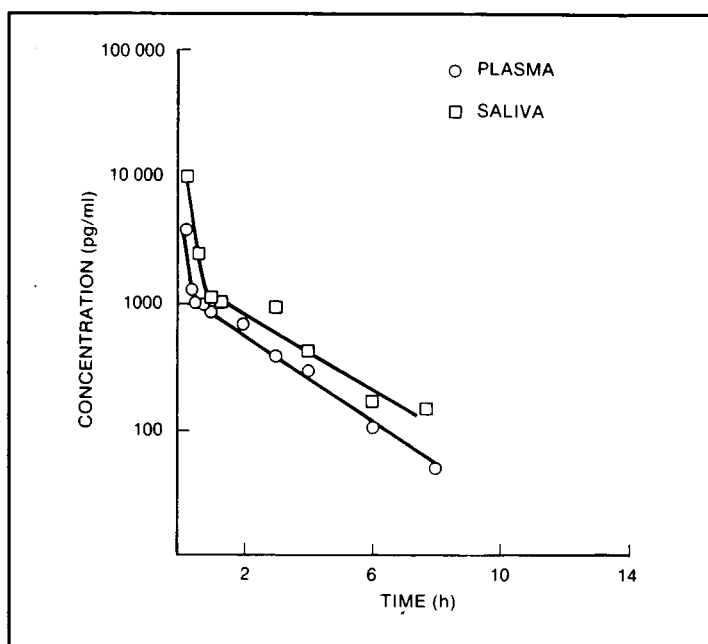
Development of a Cell Culture Bioreactor for Microgravity

PI: David A. Wolf, M.D./SD4
       Ray. P. Schwarz/SD4
       Charles D. Anderson/SD4
Reference OSSA 8

Tissue culture on Earth has limitations imposed by the presence of gravity. By nature, the growing cell systems have varying densities, usually greater than culture media, and therefore sediment within conventional culture vessels. Impellers or air lift mechanisms are utilized to maintain the homogeneous distribution of cells, nutrients, and waste products required to maintain a healthy culture. Such mechanisms disrupt natural cell processes and in many cases damage or kill delicate cells. Microgravity is anticipated to allow cultures to remain evenly suspended, in three dimensions, without introducing damaging mixing forces. The Biotechnology Laboratories of the Biomedical Laboratories Branch have developed a technique for Earth-based tissue culture which simulates select aspects of microgravity. The living cells are suspended inside a rotating cylindrical vessel which is completely filled with culture media. No damaging mechanical mechanisms are introduced into the culture. Initial tests of this system indicate superior culture characteristics. Delicate cells have been cultured at very high densities and unique associations of cells into tissue-like groups have been observed. Researchers are interested in exploring this mode of culture to determine if it is a better model for the way normal or cancer tissues grow in the human body, allowing highly controlled studies. In some cases this rotating, or clinostatic, culture technique provides a practical method to culture sufficient numbers of delicate cells for further studies. The clinostatic cultures are limited by gravity effects and only randomize the gravity vector, rather than eliminate it. The Earth-based clinostats themselves are a valuable NASA spinoff, but true spaceflight experiments are required to fully understand the potential advantages and effects of microgravity on living cell systems.

The Space Bioreactor incorporates a group of technologies which make precision tissue culture practical in space. It also has the clinostatic features described above, which allow Earth-based projections of microgravity results. The culture medium is circulated through the living culture and around an external "life support loop," as shown in the figure. In this external loop, adjustments are made in response to chemical sensors which maintain constant conditions within the cell culture vessel. PH is corrected by controlling carbon dioxide pressures and introducing acids or bases. Oxygen, nitrogen, and carbon dioxide dissolved gas concentrations are maintained by a closed loop gas exchange system in order to support cell respiration. The closed loop adds oxygen and removes carbon dioxide from a circulating gas capacitance. In this way the minimum amount of stored gases may be taken into space. Sensors which monitor dissolved biochemicals in the media are grouped into a flow injection analyzer which samples small quantities of media from multiple points in the bioreactor. A real-time process control computer collects sensor data and determines corrective actions for the various system effectors. This computer drives the displays, accepts user inputs, logs data, and produces caution and warning alerts for out of range parameters. The integrated system will allow precision cell culture experiments to be accomplished in the microgravity environment of space.

The NASA Space Bioreactor is a research tool which will produce data important for basic and applied biological sciences. This information will support the evaluation and development of biotechnologies thought to be essential for long-duration space missions. Mars mission, Moon base, and space colonies are anticipated to require biological components for their life support systems. Cultured algae and plant cells may efficiently and reliably convert carbon dioxide to oxygen, purify water, and grow foods or food additives. The field of biotechnology may utilize the unique culture conditions of microgravity to produce valuable products such as hormones and enzymes. The space bioreactor and associated cell science program are anticipated to exploit microgravity as a tool to overcome gravity limitations encountered in key areas of Earth-based research.

A laboratory prototype Space Bioreactor. The horizontal reactor vessel is visible in the lower front section of the unit.
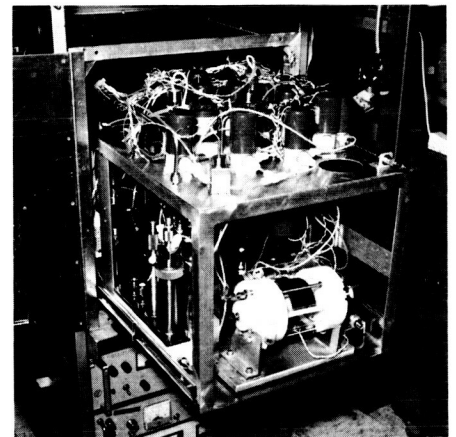
Simplified schematic of main media circulation loop.
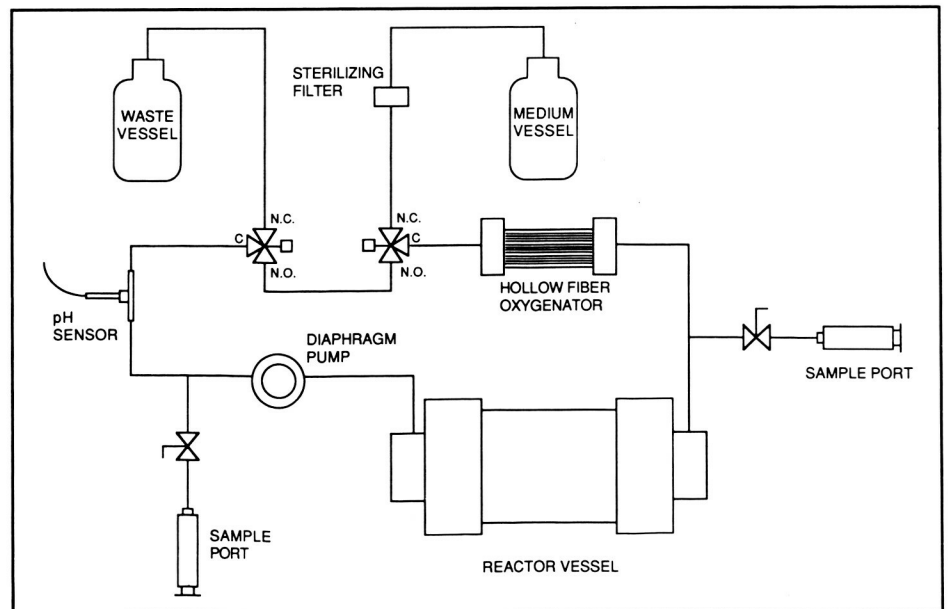
Cell Science Research in Simulated Microgravity

PI: David A. Wolf, M.D./SD4
      Marian L. Lewis, Ph.D./SD4
      Thomas J. Goodwin, M.S./SD4
Reference OSSA 9

Microgravity can provide a unique environment for studying living cellular systems. Earth-based research directed toward the understanding of tissue formation and function, cell interactions, metabolism, and secretory processes is constrained by the presence of gravity. By controlling the gravity vector as an experimental variable, we are able to acquire new knowledge of living cellular processes. Initial ground-based studies have utilized NASA-designed· precision tissue culture devices, called bioreactors, to control the culture environment with respect to gas exchange, nutrients, and waste products. The NASA bioreactors designed and developed by the Biotechnology Laboratories of the Biomedical Laboratories Branch incorporate features for controlling the direction of the gravity vector by rotating a zero-head-space culture vessel. This "randomization" of gravity allows ground-based studies which to some degree simulate microgravity tissue culture. The cultures maintained in the NASA system have a 3-dimensional freedom for cell and substrate interactions. The culture environment is extremely quiescent and free of the high fluid velocity gradients and sedimentation effects found in conventional culture systems. These unique properties allow "tissue-like" aggregations of growing cells to be studied under precisely controlled conditions. Very high growth rates and viability are observed for delicate cell types cultured in this simulated microgravity environment, as shown in the first figure.

Multiple cell studies have been initially directed toward mammalian and plant tissue cultured in simulated microgravity. This series of studies has focused on establishing the feasibility and potential for extended research in microgravity for a wide variety of cell systems. The quiescent culture environment has demonstrated the capability for growing normal human embryonic kidney cells to high density on microcarrier beads. The collagen-coated microcarrier beads provide the attachment substrate required by most normal mammalian cells. Baby hamster kidney cells, also grown on beads as shown in the second figure, show the spontaneous assembly of cells and beads into groups which approach tissue density. The culture techniques are also able to grow the large numbers of human cancer cells required for research. The colon cancer cell line (HT-29), already tested, demonstrated tumor-like aggregations of malignant cells similar to *in vitro* tumor growth. Further studies will be directed toward developing a living 3-dimensional model for studying tumor invasion of normal tissues. Advanced biochemical techniques, such as fluorescent tagged antibodies, are utilized to study the internal "cell skeletons" and secretory processes. The different pattern of structural proteins observed in cells cultured in simulated microgravity will help scientists understand the mechanisms of cellular responses to their environment. Tobacco callus plant cells grown in simulated microgravity demonstrate many of the subcellular organelle changes observed in actual spaceflight. Changes in the Golgi apparatus, endoplasmic reticulum, and statolith positions would be expected to influence cell metabolism. The ground-based studies in simulated microgravity will develop a data base required first to select in-flight experiments and then to interpret results. An added benefit of this NASA research is the spinoff value of the unique tissue culture instrumentation under development.

Tissue culture in microgravity is of interest to NASA for a variety of reasons, including basic cell science, life support systems, and potential future space commercialization. Understanding microgravity effects at the cellular level will help us to understand and develop countermeasures to the negative effects observed in persons exposed to microgravity. These include bone loss and other physiologic effects. The rapidly growing field of biotechnology will utilize information gained from the NASA cell science program to develop improved processes for producing valuable cell products. Clinical research will address understanding and treating cancers. Closed environmental life support systems required for long duration space missions are expected to utilize living biological components for atmosphere regeneration, nutrition, and water reclamation. The NASA JSC cell science program will acquire basic information required to assess performance and ultimately to design such systems for microgravity use.

A typical cell growth rate.
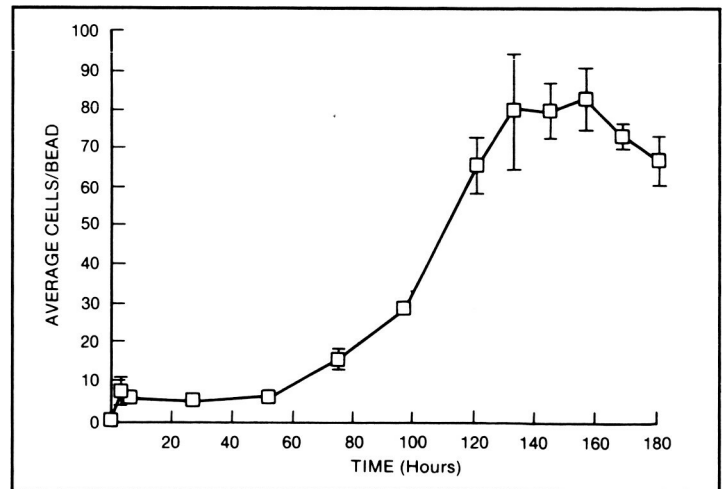
Three dimensional cell growth on microcarrier beads.
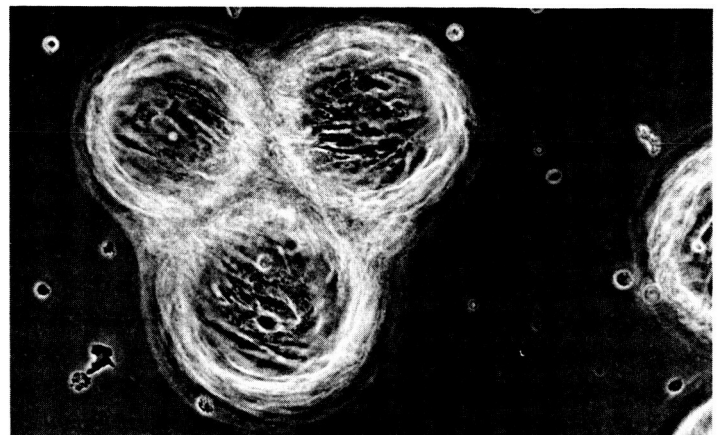
Mode C Preflight Adaptation Trainer

PI: J. Harris/SD5
        R. Parker/SD5
        M. Reschke/SD5
        D. Harm/SD5
Reference OSSA 10

NASA JSC is developing a series of trainers for preadapting astronauts to some of the sensory rearrangements (conflicts) believed to be responsible for space motion sickness (SMS). The purpose of these devices is to help prevent or reduce the symptoms of SMS experienced by crewmembers while adapting to microgravity. This will be accomplished by preflight training in devices designed to simulate some of the peculiar sensory rearrangements produced by the absence of gravity in spaceflight.

The prototype in the series of trainers is a tilt-translation device called Mode C. This Preflight Adaptation Trainer (PAT) has a chair restraint in which the astronaut trainee sits, surrounded by a rectangular enclosure. The chair can tilt in either the pitch or roll planes up to ±20°, and the enclosure translates on the pitching restraint support up to 36 inches. Precise movement of both the chair and the enclosure is provided by microcomputer-controlled hydraulic actuators.

The microcomputer program allows the trainee tilt angle and the enclosure position to be independently controlled. By selecting appropriate relationships between the amplitude, phase angle, and waveform shape for the movements, the operator will allow the trainee to experience some of the aspects of moving around in a microgravity environment. Current plans call for the device to be upgraded in the future to allow interactive control by the trainee, using force plates on the ends and handrails along the sides of the enclosure. The trainee will be able to push on the force plates and push or pull on the handrails, just as would be the case when moving around in spaceflight. The trainee should feel himself to be moving linearly as if inside a stationary room. In the trainer the trainee moves in pitch or roll only; however, movement of the visual surround with respect to the trainee induces the feeling of moving along a straight line.

A key aspect of this PAT is the use of small tilts, in combination with a static gravitational field, to simulate linear acceleration to the trainee. NASA scientists believe that during adaptation to microgravity, the brain must learn to reinterpret output from the gravity receptors as only meaning linear or translational acceleration, since there is no useful gravity field available in spaceflight to provide head/body tilt information.

With the use of this and other PAT's, the astronauts should learn to be comfortable with unusual/novel relationships between the visual and other sensory information, which may reduce adaptation time and space motion sickness symptoms in orbit. The anticipated benefits of PAT include (1) improvements in health, well-being, and comfort of crewmembers, (2) less reliance on anti-motion sickness drugs, with their consequent side effects, (3) improvements in crew performance and ability to respond quickly and effectively in emergency or other critical situations, particularly during the initial days of a mission, reentry, and landing.

Mode C Preflight Adaptation Trainer (tilt-translation device).
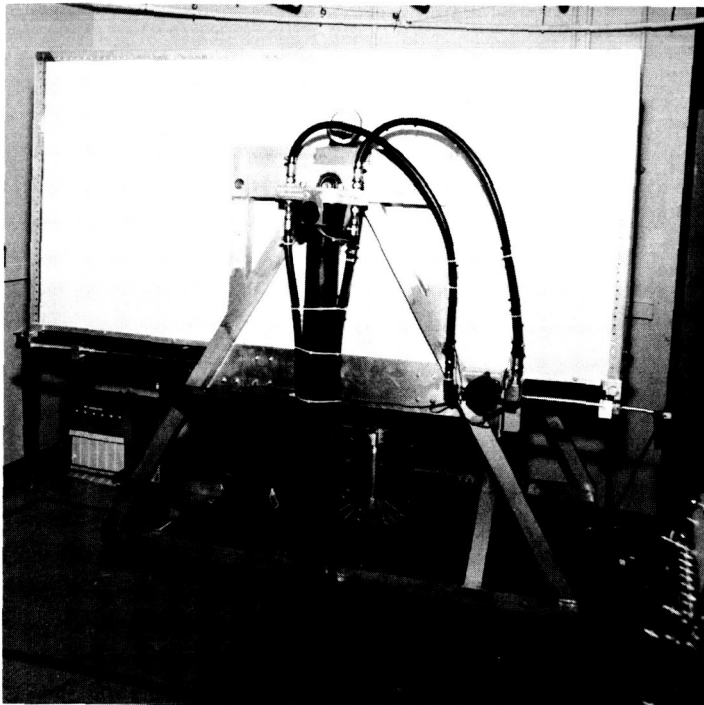
Inside view of the Mode C Preflight Adaptation Trainer (tilt-translation device).

Retinal Fluorescein Angiography During Simulated Extravehicular Activity

TM: James M. Waligora/SD5
     David J. Horrigan, Jr./SD5
PI: Richard Meehan/SD4 (UTMB)
     James P. Bagian/CB
Reference OSSA 11

Current denitrogenation protocols for planned and contingency extravehicular activity (EVA) cause intravascular bubbles and symptoms of decompression sickness among some subjects during hypobaric chamber studies. Animal studies have documented that decompression can alter the integrity of central nervous system blood vessels (blood-brain barrier) and that circulating platelets can aggregate in vivo and occlude vessels. Because these studies have used invasive methods, it is difficult to obtain comparable data from humans. Therefore, it is unknown whether intra-vascular bubbles during simulated EVA might also activate platelets in vivo and cause vascular injury or thrombosis by forming platelet aggregates or producing vasoactive substances.

The intravenous fluorescein angiography is relatively noninvasive method of directly visualizing retinal arteries and veins (200 μm to 20 μm in width), determining retinal blood flow, and assessing the integrity of the blood-retinal barrier. Because the retinal blood vessels are analagous to intracerebral vessels, both anatomically and in response to physiologic alterations, the ocular fundus provides valuable information regarding cerebral circulation.

In collaboration with investigators at the U.S. Army Research Institute of Environmental Medicine, Harvard University, the University of Colorado, and the University of Iowa, we have performed multiple fluorescein angiograms on 17 soldiers at sea level and after residing at 14,100 feet (Pikes Peak) for 17 days. Fluorescein leakage was observed in three subjects and a small retinal hemorrhage occurred in one.

We plan to extend these studies by performing fluorescein angiography with the Kowa R RC-2 portable fundus camera on subjects in the NASA JSC hypobaric chamber. This should provide investigators and flight surgeons with objective data and images of retinal blood vessels during simulated EVA conditions. This study should allow us to determine whether retinal vessels become occluded (by platelet aggregates or intravascular bubbles) or whether the blood-retinal barrier is disrupted by the generation of decompression-induced gas emboli. A better understanding of the pathogenesis of decompression sickness should facilitate the identification of optimal denitrogenation protocols and lead to more effective countermeasures to reduce the risks associated with extravehicular activity.

Operation of fundus camera in altitude chamber.
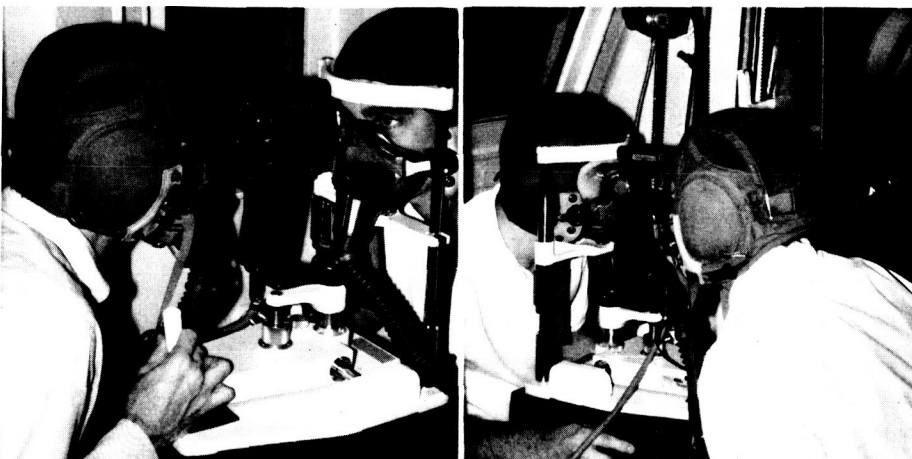
Retinal vessels photographed with fundus camera.
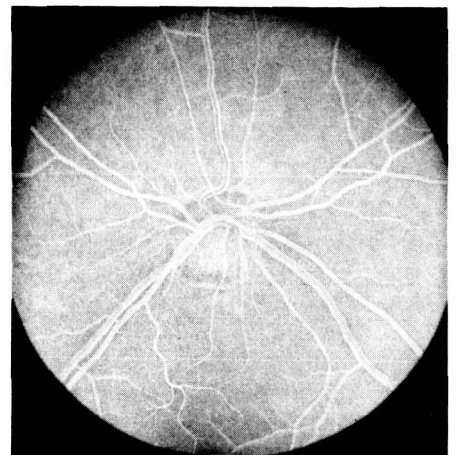
Implementation of the Medical Information Bus (IEEE P1073) for the Space Station Health Maintenance Facility

TM: David K. Broadwell/SD12
PI: David. V. Ostler/SD12
Reference OSSA 12

A top priority for the Space Station Health Maintenance Facility (HMF) is integration of the data from the various subsystem instruments into the electronic medical record contained in the HMF Medical Decision Support System (MDSS). A prototype of the Medical Information Bus (MIB) has been developed to provide this integration.

The MIB is a communications standard under development for use in a hospital intensive care unit (ICU) setting. Individual integration of medical instruments is an expensive process because each instrument requires a custom software and hardware interface. The MIB will allow medical instrument manufacturers to use a standard hardware and software interface to connect to a bedside or ICU computer. Instruments designed in compliance with the MIB standard can then be integrated with the computer system without any hardware modification. The computer system will recognize the instrument and the information sent by the instrument. Software modification is minimized because the MIB will provide a common application interface.

The MIB consists of the components shown in the first figure. The Device Communications Controller (DCC) is the interface between the MIB and a medical instrument. The Bedside Communications Controller (BCC) provides the connection between the MIB bedside network and the computer system.

The DCC prototype was designed with one hardware interface to a medical instrument and one hardware interface to the MIB. The generic DCC has the following functions: (1) To process MIB commands from the host, (2) to process data received from the medical instrument, (3) to save local data values, (4) to sample parameters from the medical instrument as requested by the host, and (5) to maintain relatively accurate system time for sampling and data reporting.

The BCC prototype was designed to accommodate up to sixteen MIB port interfaces and one interface to a host computer system. The BCC uses the same hardware as the DCC by multiplexing the single MIB interface to sixteen MIB ports.

Software for our DCC prototype is based on a multitasking approach illustrated in the second figure. One task processes MIB requests to make entries into local data storage tables or to send data requests to the medical instrument via a translation table. A second task directly processes data from the medical instrument interface into local data storage tables or directly into MIB commands via a translation table. A third task coordinates the data in local storage, coordinates data from the local time clock, makes requests from the medical instrument interface, and sends MIB messages, based on a periodic sampling request queue that is established by MIB requests from the host. New devices are interfaced to the DCC by changing the hardware interface driver and changing the instrument interface table to reflect the software protocols of the medical instrument.

This effort has proven the feasibility of building the MIB interface and can be used as a model for developing MIB interfaces by medical instrument vendors. NASA's commitment to using the MIB for medical instrument interfaces will ensure that new commercial instruments will be easily adaptable to the HMF and the MDSS.
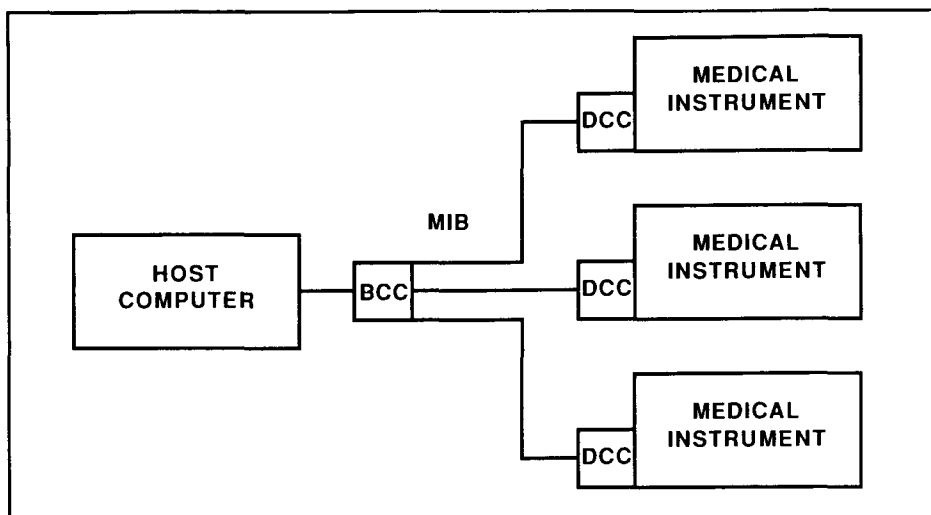
The structure of a simple MIB network.

The multitasking approach of the Device Communications Controller (DCC) software.
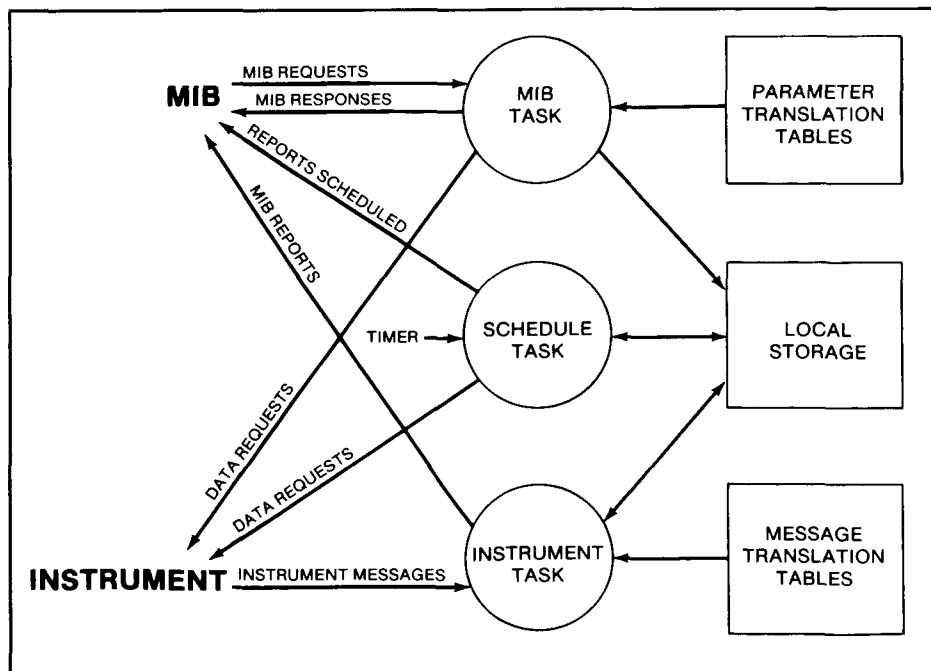
Zero-G Laryngoscopy and Oral Endotracheal Intubation

TM: David K. Broadwell/SD12
PI: John M. Shulz/SD12
Reference OSSA 13

The risk of an astronaut having an airway management problem requiring tracheal intubation during a mission cannot be accurately determined. However, many people feel that the lack of gravity increases the risk of foreign body aspiration. The potentially disastrous consequences of inadequate management of airway problems dictates that appropriate, definitive airway management procedures be integrated into the spaceflight medical armamentarium.

The definitive management of many airway/respiratory problems requires tracheal intubation with a cuffed endotracheal or tracheostomy tube. An endotracheal tube is utilized whenever possible, since a tracheostomy requires minor surgery. The endotracheal tube can be placed into the trachea through a patient's nose or mouth either blindly (without visualizing the vocal cords), or under direct visualization with a standard or fiberoptic laryngoscope. The most common method of insertion is orally, using direct visualization of the vocal cords with a standard laryngoscope.

Our goal for this study was to assess the difficulty of performing laryngoscopy and oral endotracheal intubation in simulated zero-g parabolic flight maneuvers in the NASA KSC-135 aircraft. We hoped to determine if the procedures could be accomplished while free floating and if so, would restraint of either the patient or the laryngoscopist simplify the procedure. These procedures were attempted on a Laerdal Airway Management Trainer (AMT). We also wanted to compare two different means of achieving proper orientation between the patient and laryngoscopist. A volunteer was utilized to compare the ease of obtaining adequate visualization using the laryngoscopist's knees to hold the patient's head (knee-hold) vs. using his thighs (thigh-hold) to help stabilize and orient the patient's head.

The AMT was successfully intubated free floating, as shown in the figure; but the procedure was easier to perform with either the laryngoscopist or the AMT restrained from floating free. We also noted that using the "knee-hold" provided greater flexibility in orienting the patient for improved visualization.

Inadequate airway management, in any environment, can be disastrous. Spaceflight is not an exception. Typical management of airway problems in the terrestrial setting includes intubating the trachea with an endotracheal tube passed through the mouth under direct visualization with a laryngoscope. Our experiment showed that this procedure can be performed in zero-g. We noted that restraining either the patient or the laryngoscopist from floating free simplified this procedure. We also found that the laryngoscopist can get improved visualization of the vocal cords by using his knees, rather than thighs, to hold the patient's head in the proper orientation.

Airway Management Trainer intubation in simulated zero-gravity.

Diagnostic Radiologic Imaging for the Health Maintenance Facility

TM: David K. Broadwell/SD12
PI: Charles E. Willis/SD12
Reference OSSA 14

The Space Station Health Maintenance Facility (HMF) includes sophisticated capabilities for diagnosis, treatment, and monitoring of common medical problems that might occur during a long-duration space mission. In-flight diagnostic radiologic capabilities provide the ability to assess the severity of trauma, where permanent disability or loss of life could occur, and will influence the decision to interrupt or continue the mission. Identical diagnostic capabilities are needed for Lunar Base and Mars Mission, the other manned missions in the JSC Strategic Game Plan, as well as for remote terrestrial clinics.

Specific requirements for diagnostic radiologic imaging were identified by a contract with the Department of Radiology of the University of Texas Medical School. The radiographic imaging system will operate in a unique environment under constraints characteristic for in-flight equipment, but unusual for terrestrial systems. The imaging system must be lightweight, compact, simple, and user-friendly, must operate with extremely high reliability in microgravity, and must have low power consumption. The system must generate diagnostic quality images both for local display on the Space Station and for display and interpretation on the ground. Because no commercial product exists that satisfies these requirements, a vendor was selected by competitive procurement to design and fabricate a prototype using commercially-available technologies.

Eastman Kodak, under contract to KRUG International, is constructing a prototype radiologic imaging system based on a modified commercial x-ray tube and Kodak's Photo-Stimulable Phosphor detector technology. The tube's high voltage supply uses the Space Station's 20 kHz, 208 VAC power. The detector, in a 15 by 19 in. cassette, with a 10:1 scatter reduction grid, is attached to the patient restraint during exposure. After exposure, the cassette is inserted into a separate readout device that automatically loads the phosphor screen onto a drum scanner. The stored radiographic image is measured by scanning the screen with a laser. Phosphorescence emitted from the screen, directly related to incident x-ray intensity, is sensed by a photomultiplier. The photomultiplier signal is digitized to 12 bits and stored. Up to five images can be stored on streaming tape for local display on a high resolution video monitor or for transmission to the ground. The image information will be stored in a commercial medical image format to facilitate telecommunications between Space Station, Mission Control, and the Ground Consultant Network. In addition to video display on the ground, high resolution hardcopy images will be produced using a laser film printer.

The system will produce images with discernible resolution of 2.8 lp/mm for trunk studies and 4 lp/mm for extremities. The storage phosphor screens are erasable and reusable and require no consumables. A special adaptation of the large screen enables production of inter-oral dental x-rays. The wide dynamic range of the screens makes technique selection for the exposure much less crucial than for conventional film/screen x-ray systems. The system occupies 4 cubic feet and weighs 100 pounds. Power consumption is less than 3 kW by the tube during nominal exposures, and less than 20 kW under emergency conditions where inadvertent patient motion cannot be prevented.

Significant issues to be resolved during design, fabrication, and functional verification include definition of appropriate technique factors for planned radiologic studies; methods to assure proper alignment of source, grid, and detector; and image modification required for video display. Zero-gravity functional verification tests are planned for tube/grid/detector alignment and for the readout device. A Shuttle Flight Test of the phosphor material is being considered to quantify the rate of fogging by space radiation and to assess the screen's potential value as a reusable radiation dosimeter.

Diagnostic Radiographic Imaging System configuration within the Health Maintenance Facility.
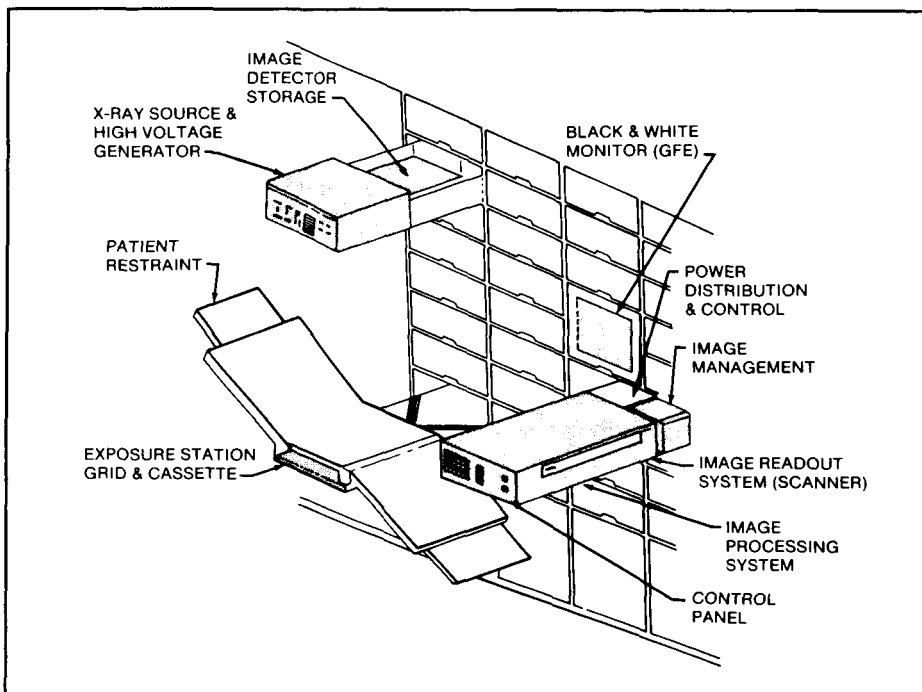
Clinical Chemistry Analyzer for the Space Station Health Maintenance Facility

TM: David K. Broadwell/SD12
PI: Bruce A. McKinley/SD12
Raymond F. Jakubowicz/Eastman Kodak Company, Rochester, NY

Clinical chemistry is a core diagnostic capability for a medical facility. A clinical chemistry analyzer for the Space Station Health Maintenance Facility (HFM) is being developed based on Eastman Kodak Company's Ektachem technology.

Dry film chemistry, a concept which Eastman Kodak Company has pioneered with its Ektachem technology, is used. The technology incorporates appropriate chemicals in amounts required for specific analyses on discrete slides of postage stamp size. Colorimetric and potentiometric analyses have been developed by Kodak. These slides are commercially available and are used with Ektachem instruments in hospital clinical laboratories.

Clinically relevant data for medical decision making is needed to provide medical care aboard the Space Station. Analyses that are essential for diagnosis, for determining and guiding therapy, and for monitoring a patient's clinical course were identified in a survey of clinician consultants. Results of this survey appear in the table of clinical chemistry requirements. All priority 1 and most priority 2 chemical analyses are available with Ektachem technology. Chemical analysis of blood, urine, and cerebrospinal fluid will be possible aboard the Space Station.

A clinical chemistry analyzer for use aboard the Space Station must have characteristics similar to other spaceflight hardware:

- Based on existing technology to save development costs
- Minimal equipment volume and weight
- Functional and reliable in microgravity and in the Earthbound setting
- Automated operation to save crew (medic) time
- Nonexpert user friendly for installation, use, and maintenance
- Computer interface available for data downlink
- Modular design (self-sufficient operation, multiple function)
- Technology upgrade potential

A clinical chemistry analyzer that meets these criteria is being designed by Kodak engineers.

The top view of the instrument design is shown in the figure. Access to the top of the instrument is required for operation. The operator will use the motorized pipette, slide carrier, keypad, and display. Other components shown are subassemblies for moving, incubating, and reading slides. Subassembly operation and data acquisition/transmission will be controlled by the instrument's microcomputer. Algorithms for chemical analyses will be those developed for commercially available instruments.

Instrument operation is automatic in concept. Operator tasks will include:

- Identifying the sample (medical patient)
- Selecting analyses from the inventory of available Ektachem slides
- Loading slides into a slide carrier
- Placing the carrier in the instrument
- Aspirating the fluid sample
- Placing the pipette in the metering station

The fluid sample to be analyzed, which is contained in a disposable pipette tip, will be automatically metered onto each slide as the slide is moved from the carrier and positioned at the pipette tip. After applying 10 microliters of the sample to each slide, the slides will be moved to incubation and reading stations. Used slides will be collected in a waste container for disposal. The results of a typical set of 8 tests will be available at the instrument display and data port within approximately 15 minutes. The results from operating sessions will be retained in the instrument's memory.

Refinement of the design will proceed with the evaluation of at least two versions of the instrument for the intended Space Station application. The development effort is being carefully coordinated with Space Station and HMF development to provide necessary configuration and performance. Clinical chemistry analysis provided by this instrument and by Kodak's Ektachem technology will support the accurate diagnosis and monitoring of disease states aboard Space Station.

Clinical chemistry analyzer design.
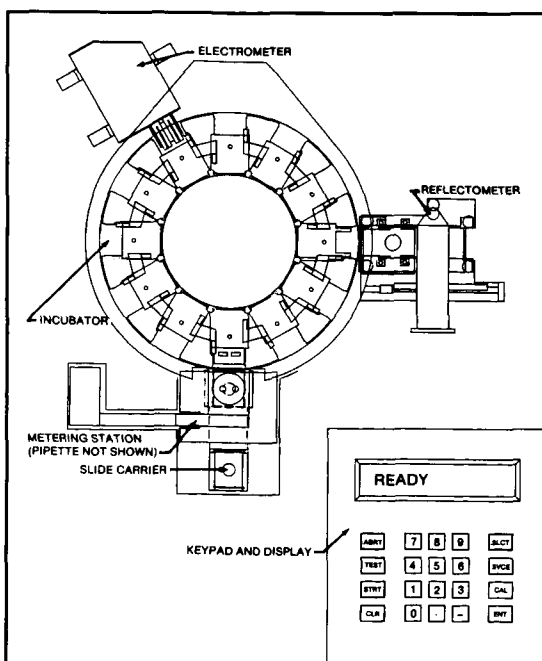
HMF CLINICAL CHEMISTRY REQUIREMENTS

	Metabolite	Electrolyte	Enzyme
Priority 1		Blood/serum	
	Glucose	Sodium	AST
	Creatinine	Potassium	ALT
	Total protein	Chloride	AlkP
	Albumin	Calcium (total) or	Amylase
	Total bilirubin	Calcium (ionized)	LDH
	Direct bilirubin	Phosphorous	
	Indirect bilirubin		
	BUN		
	Hemoglobin		
		Urine	
	Creatinine	Sodium	
	Glucose	Potassium	
	UUN		
		Cerebrospinal fluid	
	Glucose		
	Protein		
Priority 2		Blood/serum	
	Total CO_2	Calcium (total) or	GGT
	Lactate	Calcium (ionized)	CPK/MB
	Cholesterol	Magnesium	
	Uric acid		
	Fibrinogen		
	Fibrin split products		
		Urine	
	Total protein	Phosphorous	Amylase

Sterile Water for the Injection System for the Space Station Health Maintenance Facility

TM: David K. Broadwell/SD12
PI: Bruce A. McKinley/SD12
John M. Schulz/SD12
Anil Jha/Sterimatics Corp.,
Bedford, MA (Div. of Millipore Corp.)
Reference OSSA 16

Medical treatment aboard the Space Station as on Earth will rely on drugs and fluids administered to a patient as an aqueous solution. The inventory of prepared fluids in a hospital setting is extensive and typically includes those shown in the table. Depending on the injury or illness and its severity, a patient in intensive care could require more than 10 liters of fluid per day.

For Space Station, the need for minimal weight and volume dictates that such an inventory cannot be maintained in a prepared state. The approach taken by designers of the Health Maintenance Facility (HMF) is to permit formulation of these and other fluids aboard Space Station at "bedside" using sterile water for injection (WFI) produced from potable (drinking) water. A water purification cartridge has been designed by engineers at Sterimatics Corporation in cooperation with the Medical Sciences Division HMF Development Group.

Design of the purification cartridge is shown in the figure. The cartridge comprises 4 stages of purification: Prefiltration, chemical removal/deionization, ultrafiltration, and sterilizing microfiltration. All purification materials/elements are commercially available and include glass fiber, activated carbon, DI resin, and filtration devices developed by Millipore. The cartridges will be assembled, packaged, and sterilized using gamma irradiation. A one-year to two-year shelf life is expected. The cartridge, tubing, connectors, sterile WFI collection bags, and conductivity meter to check purified water quality is called Sterile Water for Injection System (SWIS). Purified water will meet USP XXI standards for WFI.

SWIS will occupy approximately 1 cubic foot within the HMF. In operation, the cartridge will be connected to a potable water supply outlet at the HMF. Water will flow through the cartridge and will be collected in 1-liter polymeric bag containers that will be sealed for immediate use or storage. Depending on the Space Station water supply design, sterile WFI may be produced at 6 liters per hour. A single cartridge will purify at least 6 liters of potable water.

Methods for formulating fluids for administration at "bedside" as needed aboard Space Station are being considered. The ability to produce fluids identified in the table is being developed.

TYPICAL PREPARED FLUIDS AVAILABLE FOR PATIENT CARE IN U.S. HOSPITALS

Prepared fluid	Single dose units
5% dextrose in water (D5W)	50, 150, 250, and 500 milliliters; 1 liter
10% dextrose in water (D10W)	1 liter
Ringer's lactate (LR)	1 liter
LR, 5% dextrose	1 liter
0.25 LR, 5% dextrose	1 liter
Normal saline (NS)	50, 100, 500 milliliters; 1 liter
Heparinized NS	500 milliliters
0.45 NS	1 liter
0.25 NS	1 liter
D5W, 0.45 NS	1 liter
D5W, 0.45 NS, K+	1 liter
Sterile water	1 liter

SWIS water purification cartridge design.
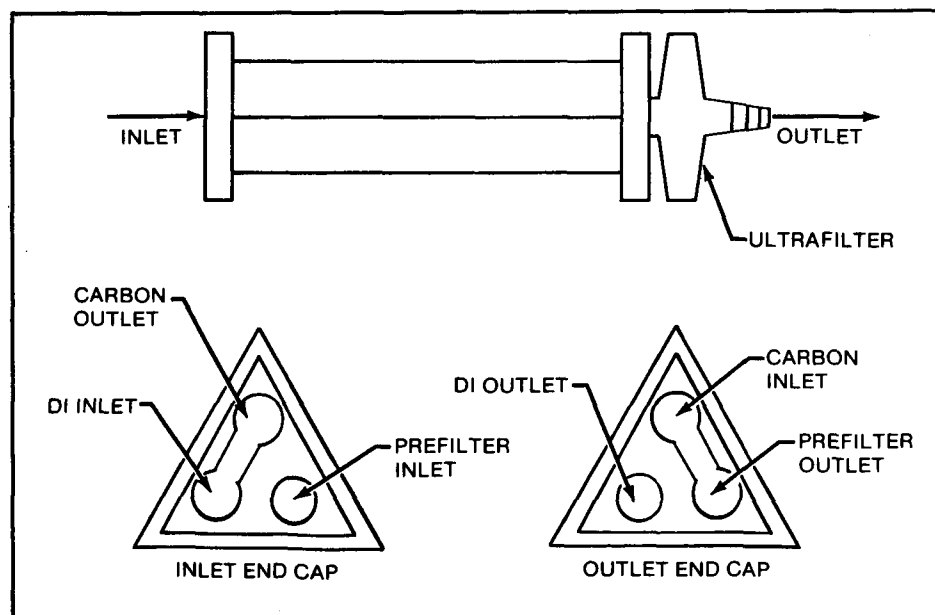
Non-Intrusive Data Collection System

PI: Frances E. Mount/SP34
Reference OSSA 17

The focus of NASA's manned space program has been directed increasingly toward commercially productive work on long duration spaceflights. Consequently, research on human factors in space, specifically, investigating ways to reduce the mental and physical effort of working in space, to minimize the time needed to do work and habitability tasks, and to increase the quality of living in space, will become an increasingly important source of information for use in spacecraft design.

Currently, most of the information concerning in-flight productivity and habitability comes from the post-flight debriefing. Since crew time is at a premium in flight, crew members do not have the time to record their own or other crewmember's behavior systematically. Therefore, any in-flight data collection system will have to make minimal demands on crewmembers.

Nonintrusive data collection methods involve recording data without intruding into or interfering with the research subject's normal activities. The most strict definition would describe a system that is unknown to and unnoticeable by the subjects of the research. The Non-Intrusive Data Collection System (NIDC) has been developed to collect data without disrupting any ongoing activities and to minimally disrupt activities prior to and after data collection.

Crew activities can be examined at several different levels: a description of a crewmember's behavior; the functions of the behavior; the visual, auditory, or other sensory information underlying the behavior; the muscular activity that produces the behavior; and the mechanics of the movements that make up the behavior. All of these different kinds of data about crew activities might have uses in the design of crew equipment and spacecraft environments. All are incorporated in the NIDC.

Guidelines have been written for the collection of physiological, biomechanical, and behavioral data.

The project has demonstrated the use of a two-channel infrared physiological data link (IPDL) as part of the data collection system. Cooperation is continuing with the Communication and Tracking Division in the development of a six-channel IPDL. A repackaging of the two-channel IPDL has taken place in an effort to minimize the intrusive aspects of the system.

Experiments are being developed to test the NIDC system on the air-bearing floor at JSC. Currently, a pilot study for an experiment determining the viability of different fasteners used on Shuttle flights is being run. The NIDC system is being used for one-g experiments in an effort to achieve an efficient and functional data collection system. A flight system is being planned.
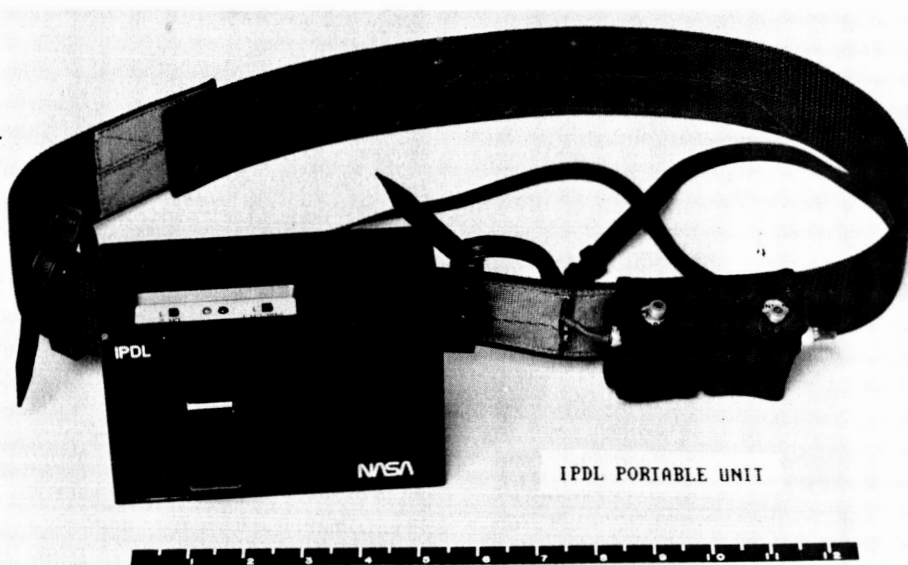
Repackaged IPDL.

IPDL used in conjunction with the human force capacity experiment.
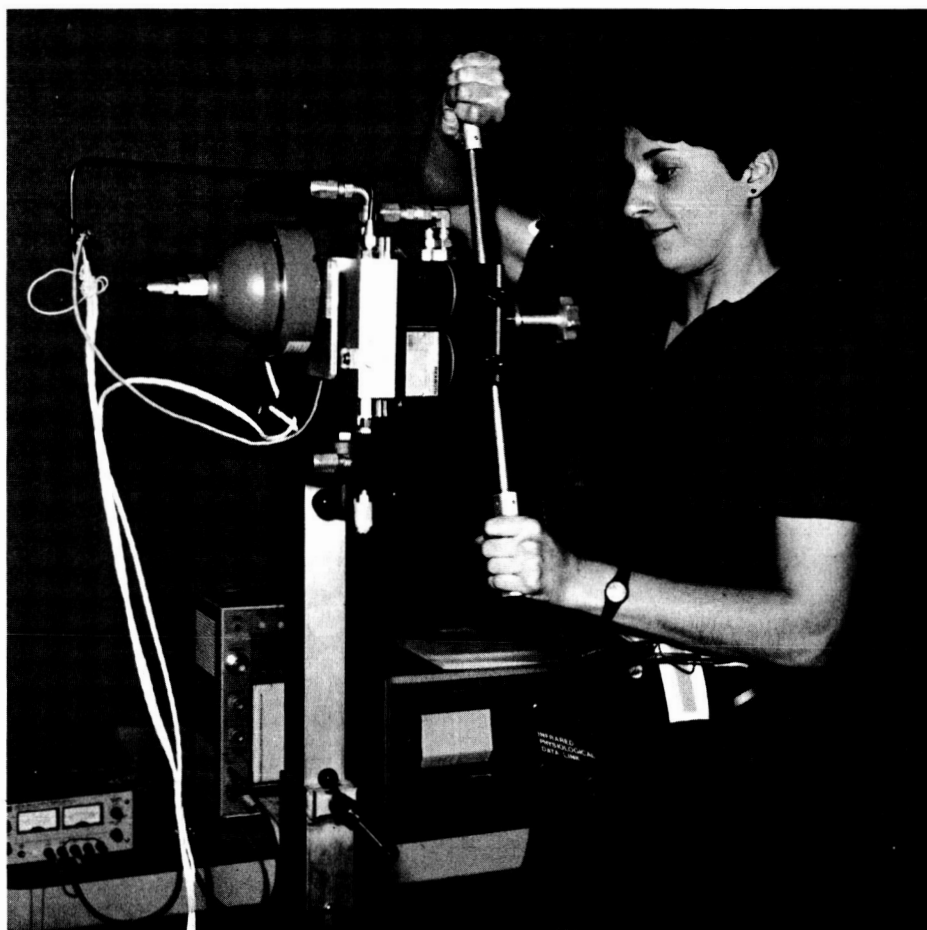
Man-Model Development

PI: Barbara Woolford/SP34

Reference OSSA 18

The computer graphics man-model, TEMPUS (not an acronym), has been used heavily in planning Space Station habitability features. This model enables the user to create bodies of specified anthropometric dimensions easily. Either precise body segment sizes can be entered, or a data base can be accessed to generate a figure of any specified percentile size. The user may easily alternate between a fifth percentile female model and a ninety-fifth percentile male model. The data base in TEMPUS is based on hundreds of measurements collected from astronauts and astronaut candidates.

Static pictures and animations can be generated. One of several default positions may be specified for a starting point. In spacecraft work, the most frequently used is the zero-g neutral body posture, in which the trunk is bent forward from the hips slightly, the head and toes are pointed down, and the knees are flexed. Starting from this position, the user may specify several constraints, such as the feet must remain attached to the foot restraints while the right hand reaches for a specific switch. If the reach can be successfully made subject to the constraints, the correct position will be generated. Otherwise, the program will report that the reach is impossible for that size figure. Once key positions are set up in this manner, animations may be automatically generated to interpolate intermediate scenes. The animation can then by played back from any viewpoint so that side views, front views, overhead views, or views from specific camera positions can be seen with no inputs from the user, other than to specify the viewpoint. This technique was used to generate an animation of two crewmembers moving a rack from the logistics module to the habitability module in Space Station. Through the animation, clearances were verified and locations for handholds were identified.

An artificial intelligence module is being added to TEMPUS to permit generation of animations from goal-directed behavior rather than from specifications of exact positions. For example, the user may be able to enter the command "Turn on Switch A" instead of "put feet in foot restraints; reach for Switch A with right hand; move Switch A up 60 degrees". This software involves both inputs in a natural language subset and procedure-oriented specifica-

tions of goal-directed behavior. It incorporates a significant knowledge base of the operator workstations and human motion patterns.
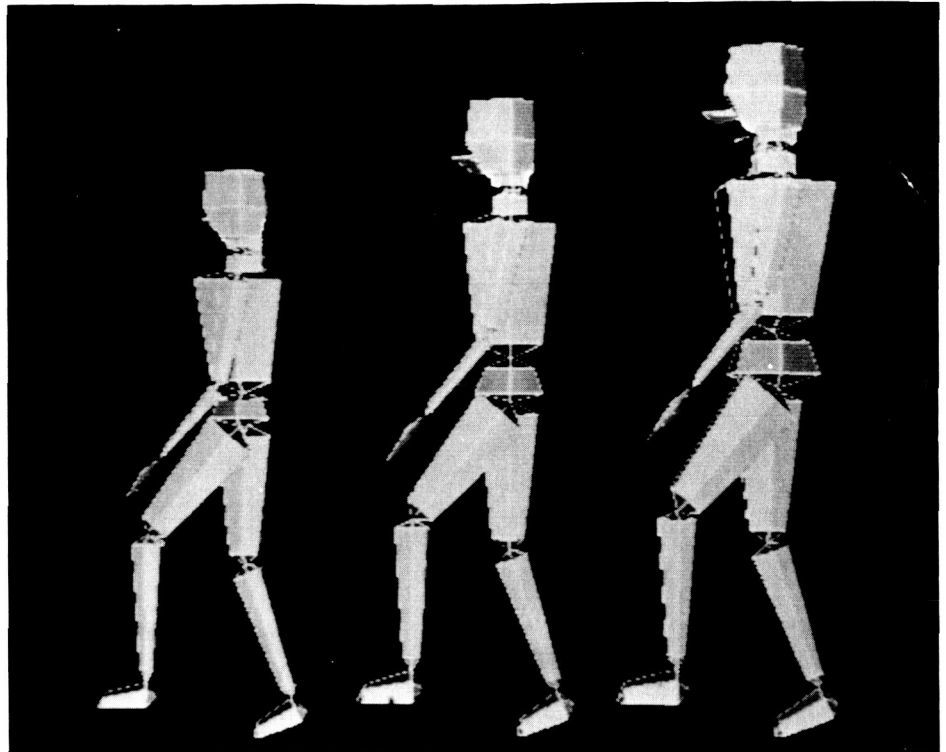
Fifth, 50th, and 95th percentile heights can be easily built through TEMPUS to position in workstations to check reach and clearances.

A body may be positioned at a workstation with a default zero-g neutral body posture and the arms repositioned automatically by specifying the points to be touched.

PICK MENU FUNCTION
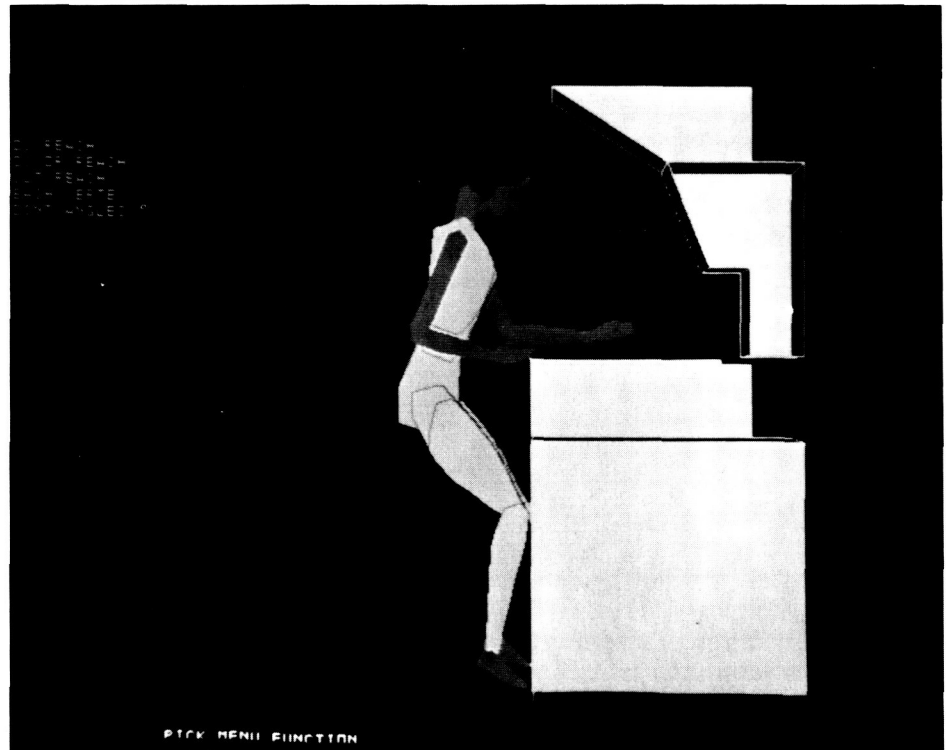
Space Sciences and Applications
Solar System Exploration

Summary

Office of Space Sciences and Applications

Solar System Exploration

Introduction

Research in planetary sciences at the Johnson Space Center (JSC) is aimed toward understanding those processes that are significant contributors to present and previous stages of planetary histories. Within the Solar System Exploration Division, studies are generally more concerned with the "terrestrial" bodies—planets within the orbit of Jupiter and the satellites of the Jovian planets. These investigations are performed by: (1) analysis of planetary materials, (2) experimental simulation of planetary conditions and processes, (3) remote-sensing observations, and (4) theoretical modeling of analytical, experimental, and observational data. This research is basic to understanding the requirements for future space missions—particularly scientific rationales and the design of mission vehicles. Highlights of recent planetary science research at JSC are described in the following summary.

Extraterrestrial Materials Studies

A fundamental part of JSC's solar system exploration effort is the study of extraterrestrial materials: lunar samples, meteorites, and cosmic dust. The lunar samples were returned by the Apollo missions, meteorites are collected yearly in Antarctica, and cosmic dust particles are collected in the Earth's stratosphere by special collectors mounted on high-altitude NASA aircraft. All these materials are curated and investigated at JSC. Because they represent samples from other parts of our solar system, these collections are invaluable.

Lunar sample studies have been fundamental in developing our understanding of the early evolution and continued development of planetary bodies and have led to major revisions in our understanding of processes for the accretion of planetesimals and the formation of planets. Studies of lunar samples have increased our understanding of impact cratering, meteoroid
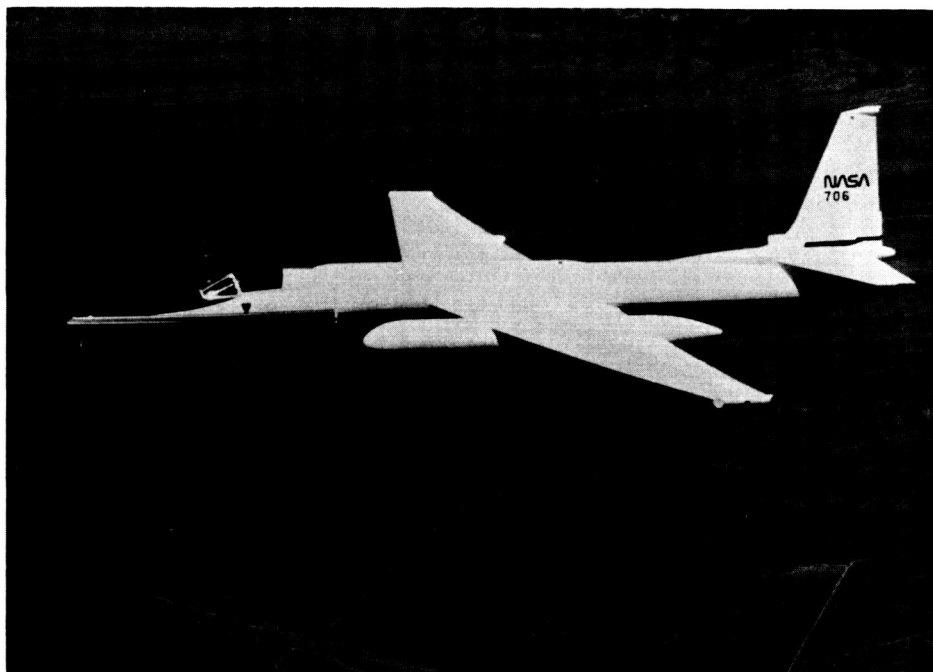
RB-57 high-altitude research aircraft in flight. This aircraft carries a cosmic dust collector which traps particles in the stratosphere for return to the laboratory.

and micrometeoroid fluxes, the interaction of planetary surfaces with radiations and particles, and even the history of the Sun. Continued study of the lunar samples at JSC and elsewhere have led to the discovery of new types of lunar rocks. For example, in the last ten years, two new lunar rock-types (very-low-titanium and very-high-potassium basalts) have been discovered through meticulous and painstaking study of the lunar sample suite. As research continues, other new rock-types are likely to be discovered in the future. Furthermore, the samples returned through the Apollo Program provide information that is required for a return to the Moon, beginning with new exploration (Lunar Geoscience Observer), followed by intensive study (new sample return missions), and eventually culminating in a lunar base and in lunar resource utilization.

Much of the information gained from meteorites cannot be obtained from any other source currently available. The records preserved in these migratory chunks of matter that have come to Earth are difficult to read, but recent meteorite studies have revolutionized our understanding of the origin and early evolution of the solar system. Meteoritics, the study of meteorites, is an attempt to answer major questions about the age and origin of the solar system, the composition of the Sun and the planets, the presence of ancient magnetic fields and heating events, and the internal and surface processes on planets and asteroids. These are clearly important questions—some of which are as old as mankind itself. Thus, the scientific value of meteorites is vast in relation to their limited quantity, and the secrets contained in these gifts from the solar system have only begun to be unraveled.

Cosmic dust, thought to be some of the most primitive material in the solar system, is also the subject of intensive scientific

A JSC scientist examines cosmic dust particles using a binocular microscope.

study. The most common sources of cosmic dust are believed to be the small bodies of the solar system, asteroids and comets, although some of the dust may come from interstellar space. Both comets and asteroids are thought to be relatively unchanged objects, left over when the larger planets formed, and dust from these objects should contain preserved clues about the origin of the solar system. Cometary dust is of particular interest and is the subject of studies by JSC scientists, because comets must have formed in the outermost fringes of the original solar system where temperatures were low enough for ices to form and survive. In these distant regions, it is possible that some of the interstellar dust particles that helped form the solar system were trapped and preserved in the icy comets.

Igneous rocks and processes

Volcanic (igneous) rocks, originating deep within solar system bodies, provide insights into the interiors of planets. Consequently, it is important to understand in detail how volcanic processes operate and how volcanic rocks form. At JSC igneous rocks are studied in many different ways. High-temperature, high-pressure laboratory experiments simulate volcanic processes; the time of the solidification of igneous rocks is determined by making precise measurements of the products of radioactive decay; field observations of terrestrial igneous rocks *in situ* illuminate relationships between different rock types; and modern computer technologies, coupled with experimental results, are used to model igneous processes that are too complicated to reproduce easily in the laboratory.

In the experimental petrology/geochemistry laboratory, a variety of experiments contains the origin of igneous rocks. Equilibrium studies investigate the chemistries of coexisting solids and liquids; these same experiments constrain the chemistries of liquids that are produced by the partial melting of planetary interiors and seek to determine how partial solidification can later change those chemistries. Kinetic experiments indicate how quickly equilibrium will be attained. Experiments carried out using complex thermal histories are used to reproduce the intricate textures observed in basalts and other igneous rocks. Thus, JSC laboratory experiments place constraints on the production and solidification of volcanic lavas and on the general formation of igneous rocks.

Knowing the ages of rocks is crucial for understanding the evolution of a planet. In the geochronology laboratory, mass spectrometric measurements are used to date the formation of planetary materials. At JSC these types of techniques have been used to date meteorities, lunar rocks, and terrestrial samples. In particular, JSC scientists pioneered a systematic study of the shergottite-nakhlite-Chassigny (SNC) meteorites, a suite of meteorites believed to be from Mars. One of the first clues that these meteorites were Martian was their formation ages. Compared to other meteorites, the SNC suite is extremely young and must have come from a planet large enough (i.e., hot enough internally) to produce recent basaltic lavas. Small bodies like the Moon cooled quickly and stopped producing significant quantities of basalts approximately three billion years ago. Conversely, the members of the SNC suite are no more than 1.3 billion years old. Thus, the comparatively young ages of the SNC's signaled that they were special rocks and not related to other basaltic meteorites. Without age information, the origin of the SNC suite would still be a mystery.

To a large degree, we can interpret volcanic rocks from the Moon and other planets only because we have previous experience from studying rocks on Earth. Consequently, field studies remain an important part of the JSC effort. Observations of rocks in the field allow complex relationships between different rocks to be deciphered. Field observations thus allow laboratory experiments and analyses to be placed in context. Lack of information concerning field relations for meteorities (and most lunar rocks) is an important piece which is missing from the meteoriticist's puzzle. The study of terrestrial field relations cannot supply the missing piece, but it can point to terrestrial rocks that may be good analogs for those meteorites whose origins are less certain.

Some igneous processes are so complex that they can only be studied by computer modeling. Multi-stage processes or extrapolations are more easily simulated by the computer than in the laboratory. For example, to understand the extensive and pervasive processes that have modified the geology of the Moon, JSC scientists turn to the computer. These attempts to unravel the Moon's differentiations are undertaken in order to estimate the Moon's bulk chemical composition. Any calculated bulk composition for the Moon will be subject to many uncertainties, but the magnitude of these uncertainties can be assessed by varying input parameters and by employing different variations of the computer model. The computer has become an indispensable tool to the planetary scientist.

Impact studies

Impact processes can change the face of a planet, can send rocks from other planets to the Earth, and perhaps can affect the course of biological evolution. The relative ages of rock formations on other planets are deciphered by noting changes in the density of impact craters on planetary surfaces (older terrains have more craters). Thus, it is important to understand the mechanics of the impact process. Several studies related to impacts are presently being carried out at JSC. Recent experiments have demonstrated that shock waves from impact events are able to efficiently implant atmospheric gases into rock. Therefore, porous, rocky materials that have been shocked during meteorite impacts may contain representative samples of the atmosphere that existed at the time of the impact. Analysis of these implanted gases, when coupled with shock ages, may allow an evaluation of how the chemistry of a planet's atmosphere has changed with time. A second type of impact experiment is being carried out in a low-gravity environment aboard a NASA airplane. These experiments are giving insight into how impact crater sizes are related to the energy of the impactor and to the gravitational attraction of the body that is impacted. Finally, the mechanics of impact are important to the study of cosmic dust particles. Before cosmic dust can be studied, it must be collected; and collection is made by a modified U-2 aircraft flying at high

speed. The dust particles impact onto a collector and are returned to the ground and the laboratory. Better understanding of the impact process will allow for better collection of these fascinating samples and will expand our understanding of the earliest solar system. Thus, the study of impact processes is crucial to a variety of investigations and is an important part of the JSC research effort.

Thermodynamics of solar system materials and processes

Chemical reactions occur only when they are thermodynamically allowed. Therefore, prediction of chemical reaction products is possible only when the thermodynamic properties of the reacting species and possible product species are known. At JSC the thermodynamic properties of planetary materials and processes are either (1) measured by differential scanning calorimetry or are (2) inferred from laboratory experiments where reactions have taken place. This type of research is of application not only to planetary processes but to engineering studies as well. Several types of materials which have been used to fabricate the Space Shuttle have been characterized thermodynamically at JSC.

Laboratory characterization of the physical properties of planetary materials

Scientists at JSC also study the physical properties of solar system materials. Recently, these types of studies have shown that the red color of Mars is most probably due to the presence of hematite (an iron oxide rust) in the Martian soils. Hematite has been shown to change its physical properties as the grain-size of the hematite crystal changes. A mixture of two different types of hematite (one with a large and one with a small grain size) can satisfactorily account for the optical and magnetic properties of the Martian surface. The presence of significant amounts of highly oxidized iron on Mars implies that the Martian surface is (or has been) a very oxidizing environment.

Remote-sensing studies of the Earth

We all know that sometimes it is difficult to see the forest for the trees and that it is sometimes necessary to step back and observe from afar. Similarly, terrestrial features of large areal extent are sometimes better studied remotely from the Space Shuttle or by satellite imaging. Scientists at JSC have used photographs taken from space to investigate the rate of addition of
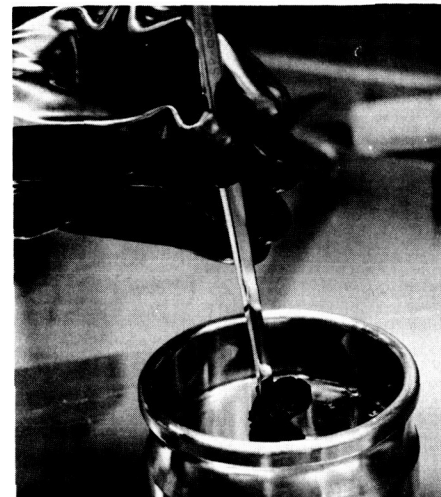
A meteorite is prepared for examination in the JSC curatorial facility.

new crust to the west coast of South America. Subduction of an oceanic plate beneath the South American continent causes melting of the underlying mantle. The melts migrate upward and produce the volcanoes that are the Andes mountains. Remote-sensing of the Andes has resulted in a reevaluation of the amount of new material that volcanic eruptions have added to South America. Thus, going into space has allowed us to understand our own planet in new and different ways.

Space Sciences and Applications
Solar System Exploration

Significant Tasks

Formation of Tonalites by Low Pressure Partial Melting

PI: James Beard/NRC
Gary Lofgren/SN4
Reference OSSA 19

Three-fourths of the Archean (more than 2.5 billion years old) crust of the Earth consists of granitic igneous rocks, most of which are tonalites (a specific composition of granitic rock). Tonalites are also common, if not quite so voluminous, in younger oceanic and arc (chains of oceanic islands) environments. There are a number of hypotheses to explain the origin of the K-poor tonalite melts. Most researchers agree that the majority of tonalites form by the partial melting of igneous rocks of basaltic composition or rocks intermediate in composition between basalt and granite at high pressure, $P > 10$ kilobars, or at intermediate pressures between 1 and 8 kilobars. The key issue here is pressure or, more specifically, water pressure during melting. In the experimental petrology laboratory at the Johnson Space Center, researchers are, for the first time, doing intermediate pressure (one kilobar) melting experiments on metamorphosed (altered elevated temperature and pressure) basaltic rocks (greenstones). Very promising preliminary results indicate that melts produced in these experiments are similar in terms of their major element chemistry to many natural tonalites, suggesting an important role for intermediate pressure processes in tonalite genesis.

The experiments consist of heating an encapsulated sample of greenstone to temperatures where partial melting of the sample is induced. These experiments were run at temperatures of between 900° C and 1000° C. The range of melt compositions generated in these experiments is essentially identical to the range of tonalite compositions observed in oceanic island arcs. A key finding for this series of experiments is that the Na/K ratio of the starting greenstone composition controls the Na/K ratio of the resultant partial melts. Natural low-K tonalites could form by the melting of crustal greenstones that have been depleted in K during the process of low-grade metamorphism.

Perhaps the most exciting finding in this series of experiments is an apparent correlation between the Fe content of experimental and natural tonalite compositions and the water vapor pressure under which they were formed. This correlation was noted when comparing our results to natural tonalite suites and to previously published experimental studies. These data are plotted in the figure. Three primary controls on the Fe content of tonalitic partial melts have been noted. These are the alkali (Na + K) and Fe content of the starting material, oxygen partial pressure, and water pressure. Of these three, water pressure appears to exercise the greatest degree of control. This conclusion is based on three observations: (1) The tonalitic melts generated in the one kilobar experiments of Spulber and Rutherford (1983), and in the JSC one kilobar experiments as well, have higher Fe contents, at a given SiO_2 content, than tonalitic melts generated at 2.5 kilobars under otherwise identical conditions. (2) The experimental melts of Helz (1976), all generated at 5 kilobars, are poorer in Fe than all lower pressure melts, despite similar starting materials and a similar range in oxygen partial pressures. (3) Natural tonal-

ites, known from mineral associations to have formed at 8-11 kilobars, are much lower in Fe than even the 5 kilobar experiments. The Fe content of both Archean tonalites and younger arc and oceanic tonalites suggest that they formed at pressures less than 5 kilobars.

A series of experiments at 2, 3, 5, and 7 kilobars are planned to test and constrain the relationship between Fe content and pressure. If preliminary observations hold, there are several important implications: (1) Many natural young tonalites that occur in oceanic arc or ocean floor settings form at pressures in the one to three kilobar range. (2) Archean tonalites probably form at pressures slightly higher than these younger tonalites, but not at "mantle" pressures (>10 kilobars). Presently, these experiments clearly favor an intermediate pressure origin for Archean tonalite magmas.

Total Fe expressed as FeO vs. SiO₂ for natural tonalite suites and experimental tonalitic melts. The experimental series of Helz (1976) on Hawaiian tholeiitic basalt at 5 kb and at the FMQ and HM oxygen buffers are shown. Experiments of Spulber and Rutherford (1983) on Hawaiian tholeiite at the graphite-methane oxygen buffer (wüstite field) at one and 2.5 kb are also shown. Eighteen JSC experiments plot in the outlined area. All are at one kb and between the NNO and HM buffers. Hi-P tonalite analyses from Sorensen (in press).
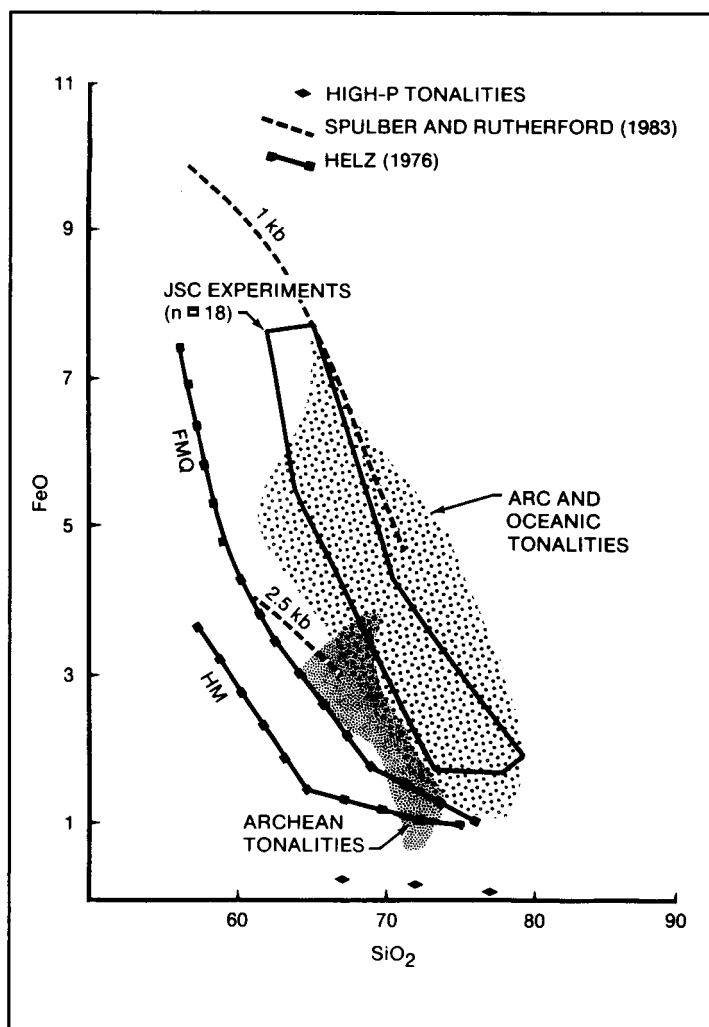
Shock Implantation of Gases Into Silicate Materials and Implications for Studies of the Martian Atmosphere

PI: Donald Bogard/SN4
      Friedrich Hörz/SN4
Reference OSSA 20

Geochemical evidence acquired over the past few years strongly suggests that an unusual class of meteorites, called shergottites, had an origin from the planet Mars. One of the strongest arguments for a Martian origin is the presence of gases (noble gases, nitrogen, and possibly carbon dioxide), in shocked phases of one shergottite, that closely resemble the composition of the Martian atmosphere. It has been proposed that Martian atmospheric gases were driven into the meteorite by a strong shock wave that accompanied a large meteorite impact on the Martian surface. Rocks that have been shock-altered, even melted, by moderate to large impacts are commonly found at craters on Earth and the Moon; but this was the first time that trapped gases within a shocked rock had been attributed to an impact event. Very little experimental evidence on shock-implanted gases existed two years ago, and it was an open question whether the Mars-like gases in this shergottite meteorite were due to a common or unusually rare set of circumstances.
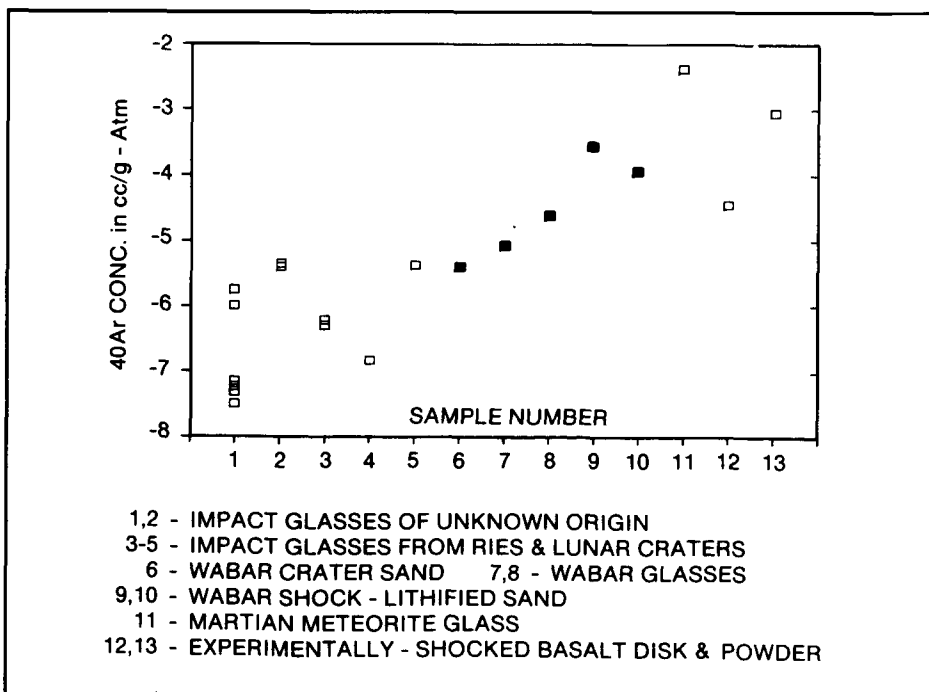
We recently have conducted experiments to characterize the phenomenon by which noble gases are implanted into silicate materials by artificially-produced shock waves, and we have searched for atmospheric noble gases shock-implanted into rocks at several large terrestrial impact craters. In these controlled shock experiments we varied the pressure and composition of the ambient gas phase, the shock pressure, the porosity of the target material, and the mineralogical composition of the target. We found that in the laboratory it is easy to shock-implant relatively large concentrations of noble gases into a variety of silicate targets. In crushed, moderately porous materials, the efficiency of the implantation approaches 100 percent of the gas available in pore spaces for shock pressures of 200,000 atmospheres and above. The efficiency of implantation does not change over a wide range of ambient gas pressures, including pressures as low as the atmospheric pressure on Mars. Neither does the implantation efficiency vary as a function of gas composition, i.e., no significant gas fractionation effects were observed. The retentivity of the shock-implanted gas (i.e., the difficulty of making the implanted gas diffuse out of the shocked sample by heating) is proportional to the shock pressure. This and other diffusion characteristics of shock-implanted gases suggest that at moderately high shock pressures the implanted gas occupies annealed microcracks within the crystal lattice and is similar in its diffusion properties to other trapped gas species. From these experimental studies we conclude that under certain, expected conditions on the Martian surface, shock associated with impact cratering could have readily introduced the observed Martian atmospheric gases into shocked phases of the shergottite meteorite.

Given the relative ease with which we were able to shock-implant noble gases into rocks in the laboratory, it would seem that shock-implanted atmospheric gases ought to be common in shocked rocks from terrestrial impact craters. However, for a variety of shocked samples analyzed in our laboratory and in other laboratories, there is little evidence for such implanted gases. Some shocked samples have lower gas concentrations than would be expected, whereas other samples have significant, lightly bound gas that is probably atmospheric gas adsorbed on chemical weathering products. The reason for the absence of obvious, shock-implanted gas in these terrestrial samples was not clear, but we speculated that it might be due to abundant ground water in the rock pores at the crater sites which served to exclude atmospheric gases at the time of impact. To test this hypothesis, we analyzed shocked samples from the relatively young Wabar, Saudi Arabia crater (90 meters in diameter) which was formed by an iron meteorite impacting into dry, mostly quartz, sand. This terrestrial site also has significant similarity to the Martian surface. Shock-lithified sand from the Wabar crater contained significant quantities of atmospheric noble gases. The figure shows ^{40}Ar concentrations for several naturally-shocked terrestrial samples, including Wabar, the Martian meteorite glass, and a basalt artificially shocked in a controlled atmosphere in the laboratory. In addition to their relatively high concentrations, the diffusion properties of noble gases in Wabar samples suggest an origin by shock implantation rather than adsorption on weathering products. The concentrations of these shock-implanted gases in shock-lithified Wabar sand are nearly as high as that observed in powdered basalt shocked in the laboratory and that observed in the shergottite meteorite if we normalize for the large (ca. a factor of 200) difference in atmospheric pressures between Earth and Mars. We believe that these studies are self-consistent and demonstrate that, under the appropriate conditions, shock associated with cratering can implant significant concentrations of atmospheric gases into porous silicates and may be a mechanism for preserving samples of ancient planetary atmospheres.

Comparison of ^{40}Ar concentrations.

1,2 - IMPACT GLASSES OF UNKNOWN ORIGIN
3-5 - IMPACT GLASSES FROM RIES & LUNAR CRATERS
6 - WABAR CRATER SAND   7,8 - WABAR GLASSES
9,10 - WABAR SHOCK - LITHIFIED SAND
11 - MARTIAN METEORITE GLASS
12,13 - EXPERIMENTALLY - SHOCKED BASALT DISK & POWDER

Impact Experiments in Reduced-Gravity Environments

PI: Mark J. Cintala/SN4
     Friedrich Hörz/SN4
Reference OSSA 21

Except for rare impacts on Earth, all collisions between solid bodies in the solar system occur at gravity levels below one-g. Only one previous experimental program, performed in a ground-based laboratory at NASA Ames Research Center attempted to address the effects of reduced gravity on impact cratering; that effort, however, was constrained by the one-g environment in which it was conducted. Various aspects of cratering research require an extended period of time immediately following the impact for study of the resulting crater, and in order to permit such investigations, it has been suggested that the Space Station be employed as a laboratory for such research.

A series of experiments was undertaken in the NASA KC-135 reduced-gravity aircraft in order to evaluate the effectiveness of that aircraft as a platform for impact-cratering research, to obtain experience in performing such experimentation at reduced gravities, and to collect scientifically useful data on the cratering process. In these studies, an air-driven pellet gun launched lead pellets into a sand target at velocities ranging from 65 to 130 m/s, as shown in the first figure. A microcomputer was used to sequence the events leading to gun-firing, to measure the projectile velocities and chamber pressure, and to record these and acceleration data for each shot. The impact itself was filmed with high-speed cameras, and the resulting craters were photographed to permit measurement of their sizes at a later time. A total of 64 separate experiments were conducted on six flights, which investigated gravity levels spanning the range of 0.054 g to 0.588 g.

All other things being equal, a projectile with a given kinetic energy will yield a larger crater as the gravitational acceleration decreases. This has been known for quite some time from theory and has been verified by both the NASA Ames experiments and others conducted at elevated gravity levels. Even over the limited range of energies available during this program, the effects of gravity are evident as shown by the graph. The relationship between crater size, projectile energy, and gravitational acceleration determined from the distribution of these data is consistent with existing predictions.

In the reduced-gravity experiments conducted at NASA Ames, the craters were formed in a target suspended by springs of various tensions, which was dropped to simulate the different gravity levels. When the target container hit its stops at the end of its fall, the craters were unavoidably destroyed. The craters formed on the KC-135 could have been preserved indefinitely, had the requirement existed. This is a significant advantage, because the targets could be hardened using established techniques and subsequently sectioned. Subsurface deformations, structural effects in the targets, and other phenomena could be examined.

High-speed motion pictures were used to determine the effects of gravitational acceleration on the time required for crater formation. While these data also appeared to be internally consistent (as do the size data in the graph), the relationship between growth time, impact energy, and gravitational acceleration obtained from them is inconsistent with existing predictions. This disagreement is not understood at present.

The KC-135 has been found to be a stable platform, conducive to impact-cratering experimentation. Data obtained during flight are comparable in quality to those collected on the ground. Experimentation at higher projectile velocities and energies would undoubtedly yield very interesting results.

The Reduced-Gravity Impact Facility in operation during flight. The impact chamber is in the background, with the pellet gun, velocity-measurement electronics, and blast deflector mounted on its lid. The motion-picture camera is mounted on the outrigger to the left, and a motor-driven 35mm camera is on the right. Video cameras attached to the pole in the right background recorded the activities during and surrounding the experiments and acted as a backup for the other two cameras. The portable microcomputer in the foreground served as both a sequencer and digital recorder for acceleration, cabin pressure, and projectile velocity data.
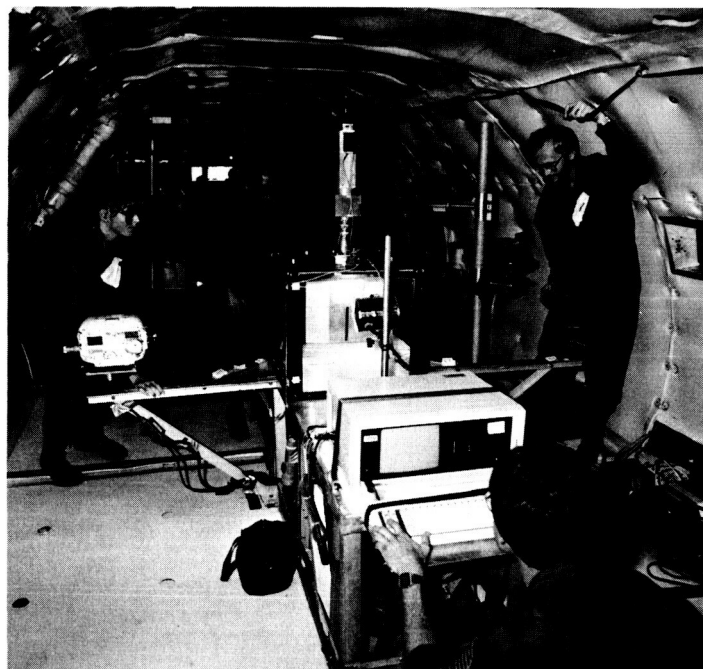
Crater diameter plotted against the impactor energy (E) divided by the gravitational acceleration (g) for 64 impacts performed in the KC-135. Note the constant growth in crater diameter as the energy/gravity term increases.
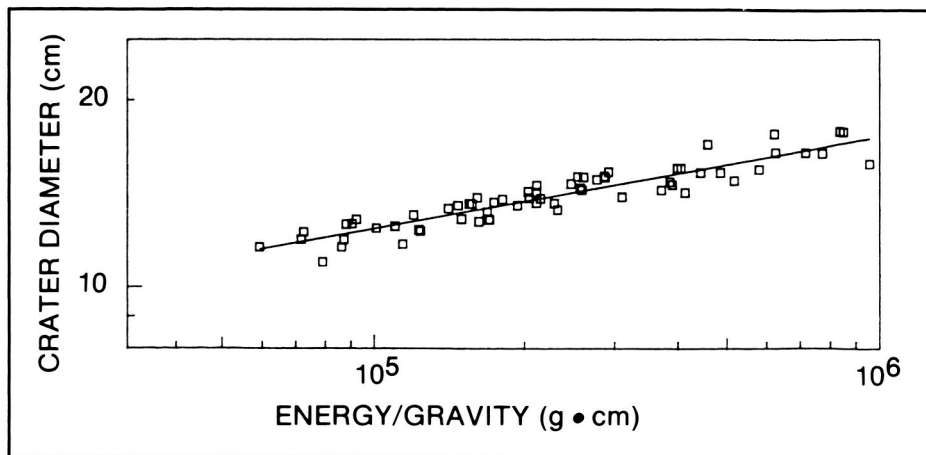
Thermodynamic Properties of Planetary and Spacecraft Materials Measured by Differential Scanning Calorimetry

PI: James L. Gooding/SN2
Reference OSSA 22

The Thermal Analysis and Calorimetry Laboratory (TACL) was constructed for basic research on the chemical-thermodynamic properties of natural extraterrestrial (planetary) materials. TACL has also served the research and development needs of the National Space Transportation System (NSTS) through thermal analyses of flight-related materials.

Reliable prediction of the chemical reactivity of a material depends on knowledge of its chemical-thermodynamic properties. For a given material, enthalpy, entropy, and free-energy values must be either measured directly or estimated from data compiled for analogous materials. The most commonly measured quantity, the temperature-dependent heat-capacity function, can be used to compute enthalpy and free-energy functions, respectively, and is usually obtained from calorimeter experiments. A differential scanning calorimeter (DSC) is slightly less precise than other types of calorimeters but offers the advantage of rapid turnaround times and much lower sample-mass requirements (milligrams vs. grams in other calorimeters).

In TACL, DSC methods are used to determine thermal stabilities, phase changes, and heat capacities of a wide range of materials over the temperature range of 100° K (-279° F) to 1000° K (1337° F). Effluent gases from the DSC can also be identified with an evolved gas analyzer (EGA) based on a quadrupole mass spectrometer. Combined DSC/EGA analyses can, therefore, be used to simultaneously characterize solid-state changes, melting or freezing, and evaporation or gas-release behavior of materials.

Planetary science work in TACL has focused on interactions of water with planetary materials at subfreezing temperatures. Although it was already well-known that nucleation of ice crystals on Earth is largely controlled by the nature and abundance of available condensation nuclei, original work in TACL demonstrated that the same effects apply under simulated Martian conditions. For a given particle size and substrate/water mass ratio, the effectiveness of ice nucleation varies widely among geologic materials (shown in the first figure); and shergottite meteorites, which are believed by some scientists to have originated on Mars, are notably poor ice nucleators. These results suggest that mud flows on Mars might persist at temperatures significantly below the equilibrium freezing point and that the nature and extent of water- or ice-cut features observed on Mars might be related, at least in part, to the nature of the soil that was entrained in the flow.

Engineering-support studies in TACL have included thermal analyses of seam putty formerly used in NSTS solid-rocket motor field joints (prior to the STS 51-L accident), metal alloys considered for use in upgraded NSTS Orbiter brake systems, and ceramic seal materials proposed for use in the NASA Standard Initiator 2 (NSI-2) pyrotechnic device. High-quality heat capacity data were obtained for the NSI-2 ceramics, for example, using individual samples of only 0.06 gram, as indicated in the second figure.

Additional studies in support of flight projects are undertaken as needed. Currently, design and analytical support is being provided for the DSC experiment to be flown in the penetrator-lander portion of the Comet Rendezvous and Asteroid Flyby (CRAF) mission that could be launched as early as 1993. The CRAF DSC will perform the first *in situ* material analyses of solids in the nucleus of a comet.

Ice nucleation as a function of substrate composition as measured by DSC in a series of Mars-analogous rocks and soils. In all cases, freezing occurs at substantially lower temperatures than for equilibrium freezing (273°K). A shergottite meteorite, which is thought by some scientists to be a Martian rock, fosters survival of undercooled water to temperatures that are nearly as low as the artificial case of heterogeneous nucleation on polished aluminum.
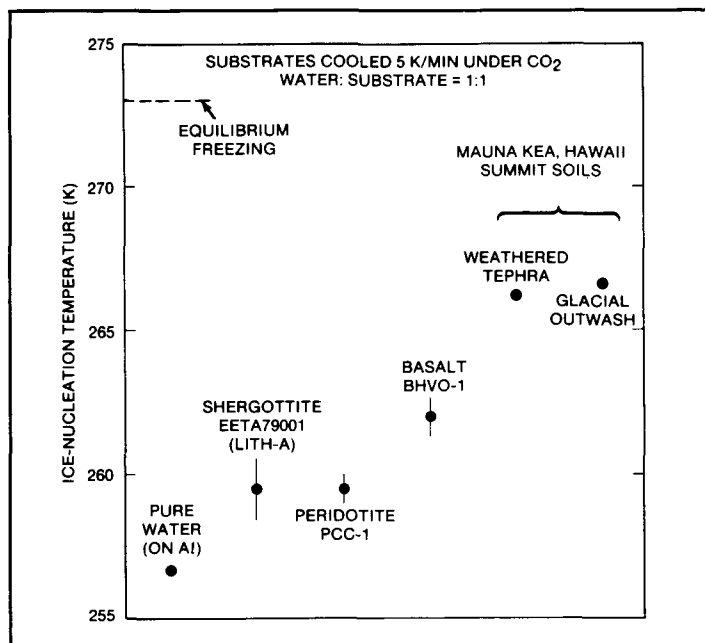
Heat-capacity function, determined by DSC, for ceramic material proposed for use in NASA Standard Initiator 2 pyrotechnic device. Using three samples of only .06 g mass, these average results were obtained with typical uncertainties of about 5 percent for each point. The broad valley at 500° to 900° K represents a second-order, solid-state phase change that was previously not recognized as a characteristic of the ceramic.
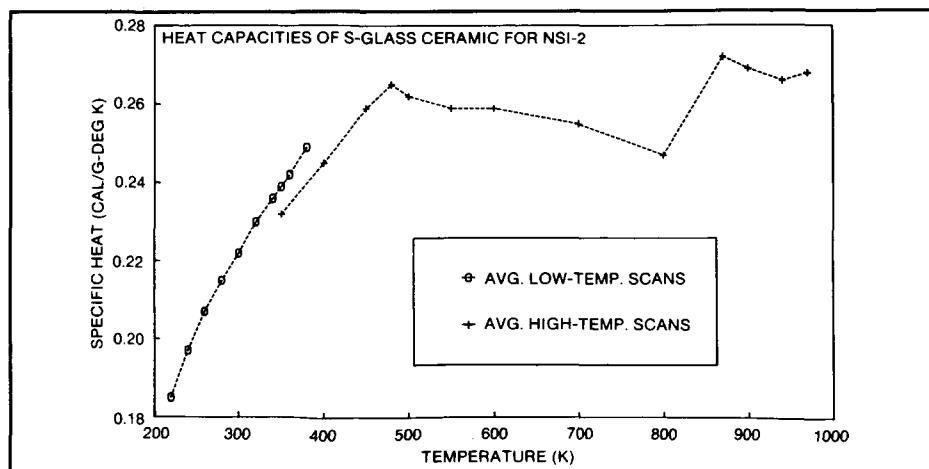
Hematite on the Surface of Mars

PI: Richard V. Morris/SN4
Reference OSSA 23

It is now possible to show that the features attributed to ferric iron in remotely-sensed spectral data (visible and near infrared) of Mars and that the magnetic nature of Martian soil at the Viking landing sites are consistent with the occurrence of hematite (α-Fe$_2$O$_3$) as both superparamagnetic hematite (sp-Hm) and larger diameter hematite (bulk-Hm) particles. The hematite particles most likely occur as the pigment within the matrix of larger (silicate?) particles or rocks. Accommodation of the Martian data by hematite is a result of differences between the optical and magnetic properties of sp-Hm and bulk-Hm. The properties of bulk-Hm are well-known. Our recent studies of synthetic sp-Hm particles have characterized the optical, magnetic, and Mössbauer properties of sp-Hm. Samples were prepared by impregnating high surface area silica gel with a ferric nitrate solution, air drying, and calcining at 550° C.

Two types of optical spectra were found. The first type is represented by the spectrum of sample S6FN25 in the first figure. As determined by Mössbauer measurements, this sample contains hematite particles larger than ~10 nm in diameter, and its optical spectrum is typical of that for bulk-Hm. The second type is represented by the optical spectra of samples S6FN18 and S6FN29. These samples contain only sp-Hm with particle diameters less than ~10 nm, and their optical spectra are significantly different from that for bulk-Hm. In particular, the band near 860 nm that is diagnostic for bulk-Hm is not resolved for sp-Hm. The spectrum (MXS15) of a mixture of these three samples and an olivine basalt (to lower the albedo) closely matches the composite spectrum of the Martian bright regions shown in the second figure.

The magnetic properties of sp-Hm are also significantly different from those of bulk-Hm. The saturation magnetization of sp-HM is more than an order of magnitude larger than that of bulk-Hm. This is due to the imperfect cancellation of the magentic sublattices that occur for sufficiently small particles (sp-Hm) but not for bulk-Hm. The saturation magnetization of sp-Hm, but not that of bulk-Hm, is sufficiently large to satisfy the constraints of the Viking magnetic properties experiment. Thus, hematite present in a wide diameter range from sp-Hm to bulk-Hm particles can account for both the features due to ferric iron in the Martian spectral data and the magnetic nature of the Martian soil.
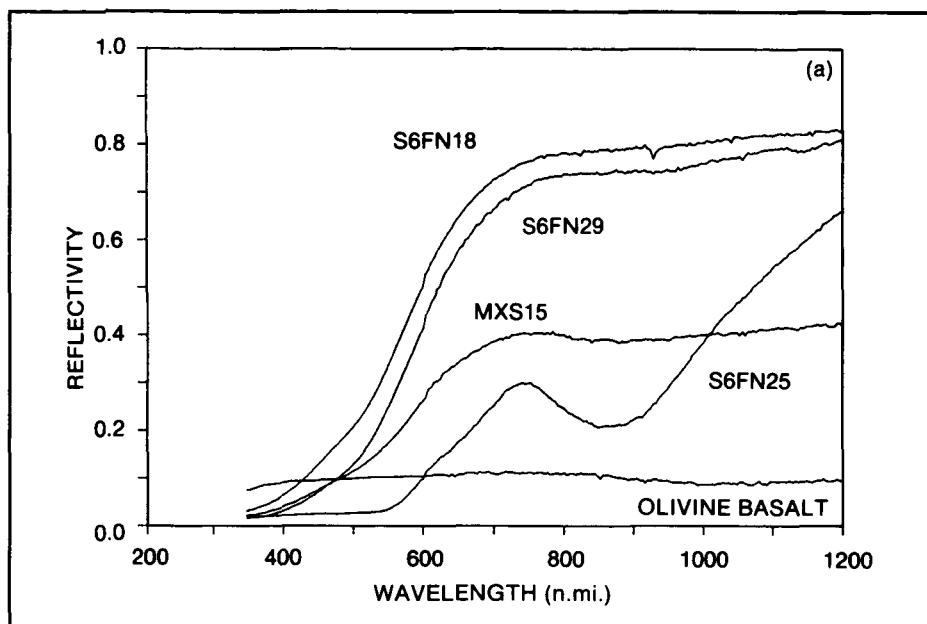
Optical spectrum of a mixture (MXS15) with a Mars-like spectral signature. Spectra of mixture components. Components were combined in the proportion S6FN18/S6FN29/S6FN27/Basalt = 42.5/42.5/4.7/10.2%.

Comparison of MXS15 with Mars bright region spectrum.
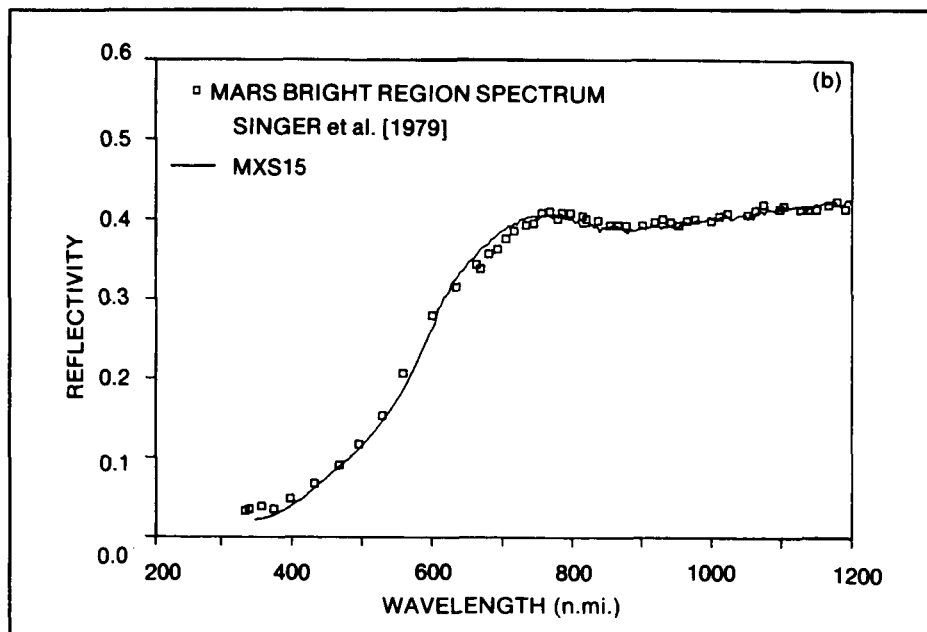
Volcanism and the Growth of the Continental Crust

PI: Charles A. Wood/SN4
      Peter Francis, Lunar and
      Planetary Institute
Reference OSSA 24

The Earth has two types of crust: *ocean floor* volcanic rocks which are observed to erupt along a network of ridges transversing ocean floors, and a much more complex *continental crust* whose formation mechanisms are less well understood. Currently, the best estimate is that most continental crust is formed at subduction zones, such as in western South America, where the ocean floor crust thrusts into and below adjacent continental crust. Subduction causes earthquakes and volcanic eruptions such as are common in the Andes mountains.

In order to better understand the processes and rates of continental crustal growth, we have investigated exactly how the crust has formed in the Andes during the last 20 million years. We have calculated how much volcanic material has been added to the crust by eruptions of volcanoes, basing our results on remote-sensing measurements of 1,100 volcanoes in the Central Andes, using photographs taken by Space Shuttle astronauts and Landsat satellite images. A key result is the recognition that considerably more material is associated with a volcano than that which constitutes the actual cone.

Using analogies with recent well-observed eruptions such as Mt. St. Helens, U.S.A. (1980) and El Chichon, Mexico (1982), we have estimated the significance of different volcanic components to crustal growth in a volcanic arc like the Andes. In particular, the recent eruptions imply that over the lifetime of a volcano, explosively erupted ash, which forms a widespread deposit around its source volcano, may have a total volume 10 times greater than that of the volcanic cone itself. Additionally, a large amount of ash is erupted into the Earth's stratosphere and is atmospherically distributed around the planet. Finally, we know from old volcanoes whose cores are exposed by erosion, that not all of the volcanic rock formed is erupted; perhaps 5 times as much as makes up the surface cone is stranded in a chamber under the volcano, thus becoming a further addition to the crust. All told, about 10 km^3 of magma has been added for each kilometer of arc length in the Central Andes for each of the last 20 million years.

There are still many uncertainties in our estimates of the various components of crustal growth by volcanism at subduction zones, but one conclusion is clear. The unseen volcanic products are much more important contributors than the conspicuous volcanoes and their nearby lava and ash flows. Volcanoes are but beacons, pointing out locations from which vast amounts of material have been ejected to affect the Earth's climate and to help construct the continental crust.

VOLCANIC CONTRIBUTIONS TO CRUSTAL GROWTH IN THE CENTRAL ANDES

Far-flung ash deposits	59%
Magma stranded in chambers	25%
Globally distributed ash	6%
Near-volcano flows	5%
Volcanic cones	5%

Young, snow-capped volcanoes along the Chile-Bolivia border (21.5° S, 68.0° W). Photo taken by astronauts on Space Shuttle mission STS-41D, September 1984.
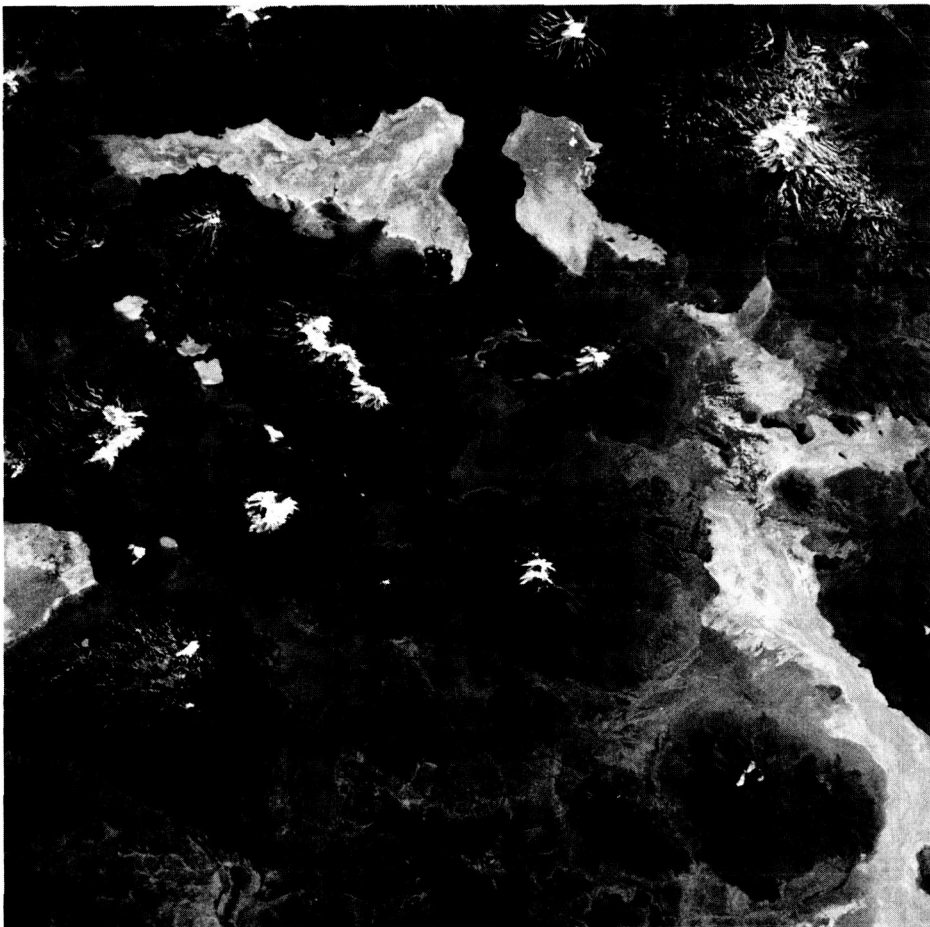
Aeronautics and Space Technology

Summary

Office of Aeronautics and Space Technology

Summary

Introduction

In Fiscal Year (FY) 1987, the Lyndon B. Johnson Space Center (JSC) developed the JSC Strategic Plan within the guidelines and context of the Agency Strategic Plan. In the course of this process, JSC identified and streamlined areas of research and technology (R&T) development needed for the NASA future initiatives. The FY 1987 R&T activities, under the sponsorship of the Office of Aeronautics and Space Technology (OAST), were pursued with vigor and are considered a cornerstone in the JSC Strategic Plan implementation. Additionally, R&T facilities were modified, repaired, updated, and sustained in preparation for resumption of flight experiment activities. The JSC efforts were sponsored under the OAST Space R&T Base Program (UPN506). JSC technical advances during this FY, under this program, were in the areas of space energy conversion, materials and structures, space data and communications, controls and guidance, human factors, space flight systems, and advanced systems analysis. These R&T areas are deemed essential for the safe and productive presence of humans in space, as well as manned/unmanned lunar base and Mars missions. The following paragraphs summarize the work being accomplished in the major R&T areas. Reports on selected tasks follow this summary.

Space Energy Conversion

Three task areas pursued under this R&T effort are: (1) two-phase thermal management system, (2) chemical heat pump for portable life support systems, and (3) supercritical oxidation of urine and feces. Two-phase systems for thermal management have shown advantages in the areas of need for reduced pumping power, system isothermality, and heat load flexibility. Consequently, such systems have been baselined for Space Station and associated free-flying platforms. However, limited infor-

mation available on liquid/vapor flow and heat transfer characteristics in the reduced gravity environment has resulted in design uncertainties. JSC has designed and developed a test stand to gain understanding of the fluid behavior, as well as to collect the needed data for space systems design. This system has been flown in the JSC KC-135 aircraft for reduced gravity testing and data collection.

To realize higher efficiency in maintaining thermal environment during an extravehicular activity (EVA), JSC has designed and developed a metal hybrid chemical heat pump. This innovative technique accomplishes transfer of waste heat without requiring either moving parts or electrical energy. Current and future efforts are being devoted to optimizing the hybrid pumping characteristics and minimizing design complexity.

Future NASA plans include a number of manned planetary explorations and the lunar base in addition to establishing permanent presence in space. For these

missions, dependence on resupply of expendable materials from Earth becomes a critical issue. In view of this, JSC has initiated a new approach to recycling waste treatment, based on supercritical water oxidation. In addition to producing heated potable water, this process can treat feces and combustible trash, remove air contaminants, provide nitrogen, and produce sterile nutrients for plant growth. This new approach can potentially be used to reduce the load on humidity condenser and carbon dioxide subsystems. Substantial progress has been made in this research at JSC, as is reported in the detailed project writeups.

Materials and Structures

JSC, in cooperation with Los Alamos National Laboratory, has developed an atomic oxygen beam facility that will be used to study the effects of atomic oxygen interactions, such as surface recession and space glow, with spacecraft surfaces.

Spacecraft glow as photographed during the STS-8 mission. The intense red spectrum of the glow results from atomic oxygen reacting with atmospheric gases (NO, NO_2) which are formed and then released from Space Shuttle surfaces.
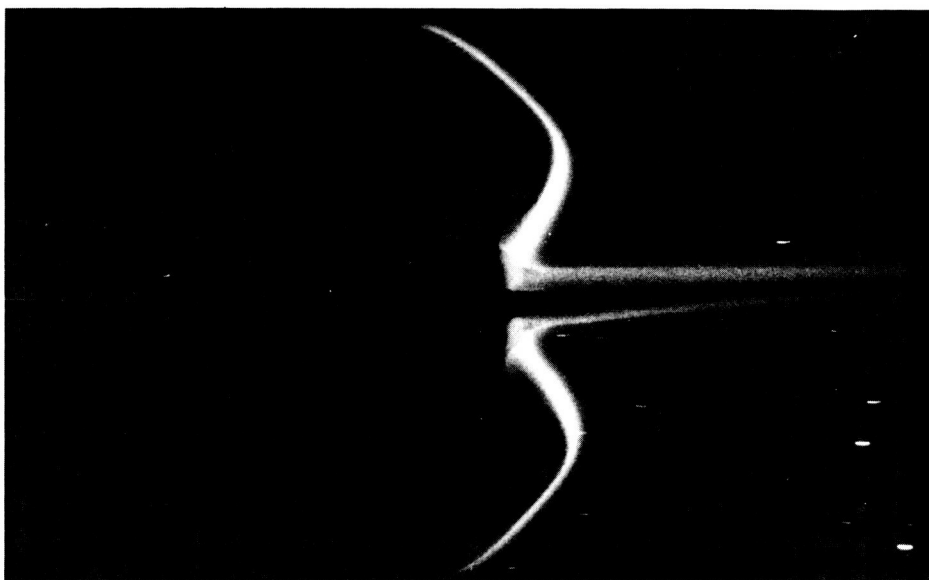
IMPACT

A sectional view of a perforated 16-lamina plate of graphite-epoxy. The plate was impacted with a 5 mg nylon projectile at a velocity of 6.7 km/sec.

Full-life certification tests of materials and coatings for Space Station will be conducted in this facility. OAST has played an important role in the development of this facility. After the initial JSC studies are completed and the facility becomes operational, other NASA Centers would be able to evaluate and select materials for their respective Space Station work packages and other missions. In another endeavor, JSC has continued testing of composite materials under potentially damaging simulated hypervelocity impacts from meteoroids and orbital debris. Experiments to assess the damage in the velocity region of 5 km/s to 7 km/s were

conducted in FY 1987. Substantial effort was expended in the standardization of these tests and the required facilities. A report describing the details of the tests has been published.

Space Data and Communication

In 1983, NASA JSC formed a research partnership with the High Technology Laboratory of the University of Houston at Clear Lake (UHCL) to study the software engineering issues associated with the Defense Department's Ada language initia-

tive. This RTOP was very successful in forming cooperative links with industry and other academic institutions. The Space Station Program's choice of the Ada language was heavily influenced by this RTOP's activities. This research partnership has evolved from an emphasis on Ada issues to the broader scope of software engineering and has resulted in the formation of the Software Engineering Research Center (SERC) at UHCL. The SERC seeks to establish a position of research leadership in the three environments critical to NASA's embedded system software development and maintenance, (1) the host or development environment, (2) the integrated (test and verification) environment, and (3) the target environment where the application software actually executes. The SERC will also enable NASA to establish a research presence in other areas of software engineering, such as innovative uses of expert systems, user interfaces, and life cycle documentation management.

Guidance and Control

The Guidance and Control (G&C) system for manned space systems and unmanned platforms provides safety- and mission-

Coordination of GN&C systems design with a Facility Management System.
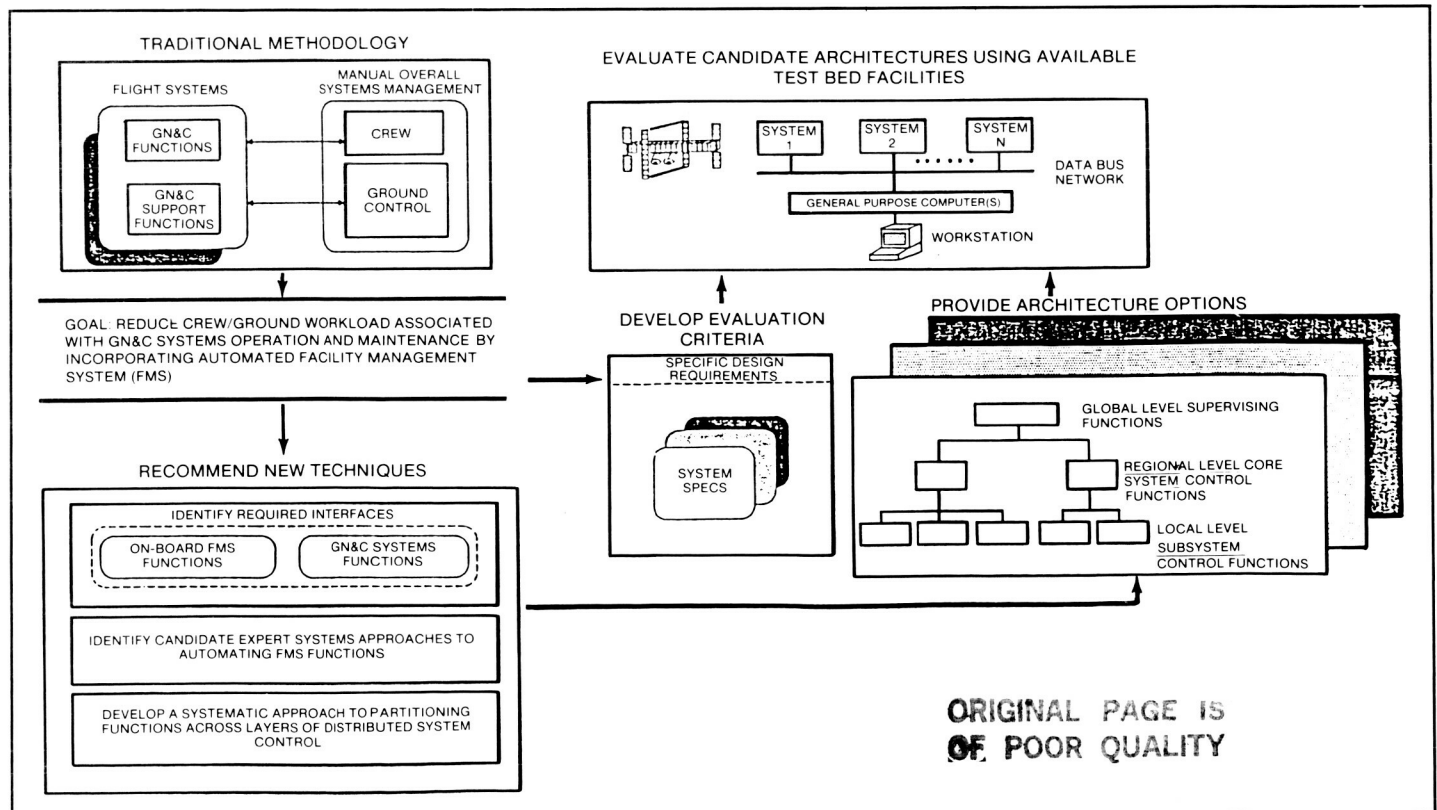
critical functions and is complex because of numerous interfaces with other systems. To meet current and future NASA program requirements, modern G&C systems must meet stringent performance demands, be highly reliable, easily verifiable, upgradeable over the operational life cycle, and maintainable on orbit. To achieve this performance, research is needed to address the G&C system architectures, system management techniques, and maintenance concepts. In the area of control and guidance, the Avionics Systems Division has directed the emphasis toward technology which has the broadest application across interacting space-fleet elements

The studies and analyses conducted at JSC promote the development of the following: (1) control technologies for integrated orbital operations and services, (2) advanced information processing system architectures, (3) the partitioning between flight management and G&C systems, and (4) fault-tolerant processor design to serve the needs of the next-generation G&C systems. In the Space Shuttle, fault tolerance is provided by a four-string system which is highly software intensive, since all the redundancy management is performed by the software. The advanced fault-tolerant processor being developed by the Avionics Systems Division implements all the non-design-specific redundancy management functions in the hardware. A redundancy

processing base is provided, which is transparent to the software applications, thus allowing for hardware upgrade over the life cycle without costly software redesign impacts. Additional investigations have been conducted to evaluate and develop methodologies for use of the Global Positioning System to provide an autonomous onboard navigation and retargeting capability for orbital transfer vehicles. An ultimate objective is to develop a space navigation system which is transportable between vehicles and mission and which does not require state vector updates from ground tracking.

Human Factors

The Space Shuttle has more than 1500 dedicated displays and controls over a hundred distinct cathode ray tube (CRT) displays with which the crew communicates with the spacecraft systems. The number of displays, controls, and CRT's in the Space Station will be substantially higher, resulting in an increased demand on crew performance. The goals of this research are to identify efficient human activity and interactive protocols and to provide requirements and guidelines for future spacecraft display and control design. The aims are to increase both safety and productivity of humans in space, as well as to advance the

understanding of the man-machine interface with increasingly complex systems. The areas of investigation include identification of mechanisms by which humans understand and analyze information, effective styles of information presentation, and optimum requirements for computer driven systems. The design of a helmet-mounted display was developed as part of the effort under this RTOP. Since physical characteristics of crew members are of utmost importance in the design of human spacecraft interfaces, the collection of anthropometric and strength data under one-gravity and simulated zero-gravity has been initiated. Models of human strength and body dimensions are being developed in a computer aided design system and will be used in the interface studies and designs.

Spaceflight Systems

The Orbiter Experiments (OEX) support the NASA OAST goals of development of technology for advanced aerospace transportation systems. The routine operation of the STS provides a unique opportunity to vastly expand the scope of flight experimentation and to obtain a wealth of benchmark R&T data throughout a broad range of flight conditions, many of which have been inaccessible to the ground-based researcher. Many OEX experiments and

Computer interface terminals will be available in the private crew quarters on Space Station.

The Health Maintenance Facility workstation is designed to interface with the onboard computer network.
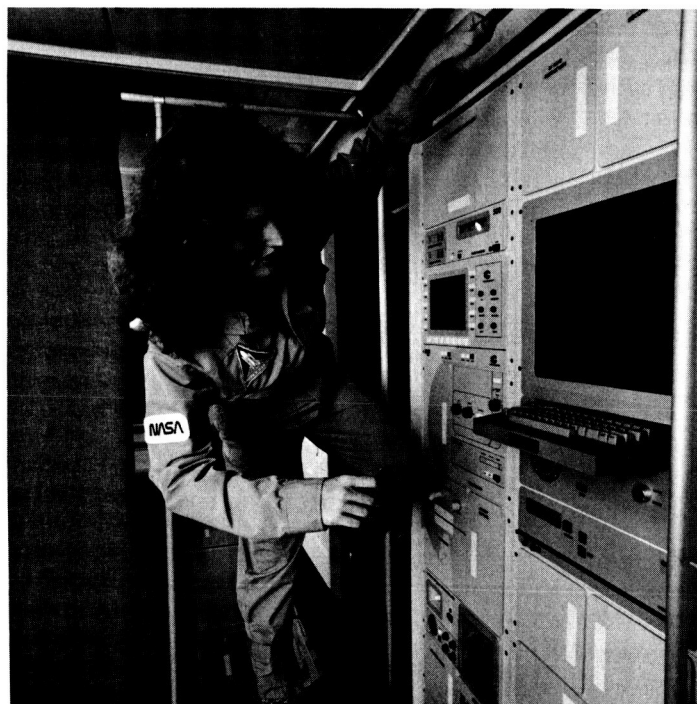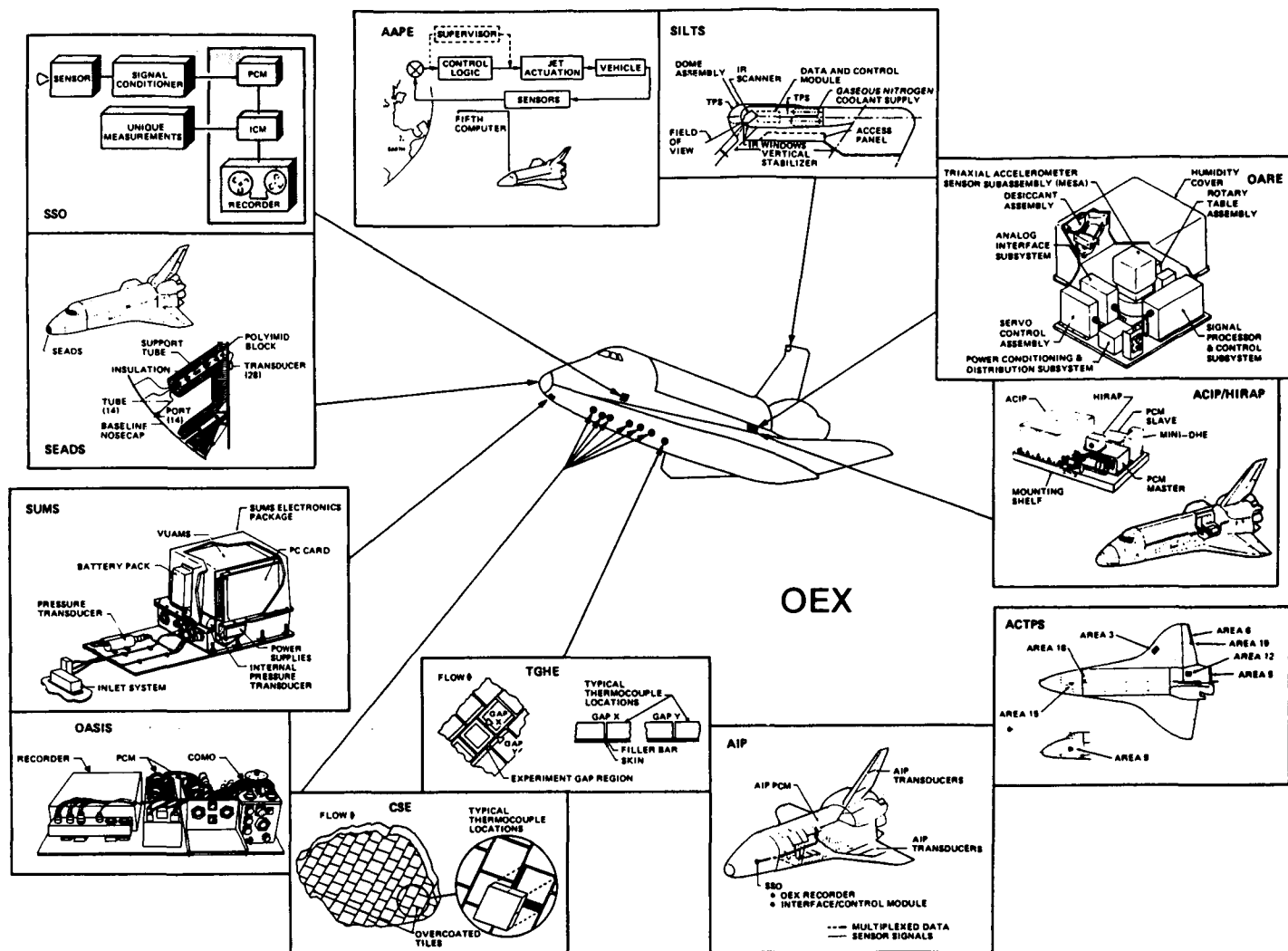
Orbiter Experiments.

research-dedicated hardware have been and will be developed for integration into the Space Shuttle to collect specific research-quality data in the technology disciplines that will augment the R&T base for future spacecraft design. The OEX Project at JSC has utilized the current Space Shuttle Program stand-down period for completion of engineering design and manufacturing of planned and approved experiment and integration hardware to allow installation on Orbiter *Columbia* prior to its next flight (STS-28). This will augment the other basic OEX experiments and data systems already on that vehicle and flown on STS 61-C. The Shuttle Infrared Leeside Temperature Sensing (SILTS) experiment was partially redesigned to correct mission 61-C problems; the Shuttle Upper Atmosphere Mass Spectrometer (SUMS) experiment was modified and recalibrated; design was completed on the Advanced Ceramics Thermal Protection System (ACTPS) Tailor-

able Advanced Blanket Insulation (TABI); manufacturing was completed and certification initiated on the Aerothermal Instrumentation Package (AIP) experiment mission kit hardware; major fabrication and engineering activities for the hardware, electronics, software, and Orbiter integration hardware were initiated for the Orbital Acceleration Research Experiment (OARE); experiment hardware and facilities at JSC, KSC, and contractor facilities were modified, repaired, updated, and sustained in preparation for resumption of flight activities.

Additional efforts under this RTOP are the development and testing of zero-g gauging technology for cryogenic fluids, and the development and testing of the Aeroassist Flight Experiment (AFE) study. JSC will deliver flight gauging system hardware for test verification on a subscale experimental flight test bed in the Cryogenic Orbital Liquid Depot Satellite (COLD-SAT) to be launched on Space Shuttle or on an

Experimental Launch Vehicle (ELV). Laboratory tests were performed to determine the sensitivity of a promising RF model gauging system concept at more realistically simulated zero-g fluid behavior modes (multiple bubbles, fluid along the tank walls) to advance the previous year's accomplishments. The RF gauging concept operated as expected, and accuracies of 5 percent are feasible. The AFE aerothermodynamics methodology document was prepared, the windward heating distribution on the AFE aerobrake was established, a preliminary design of the base flow and heating experiment (BFHE) boom has been completed, and instrument selection and integration design have been greatly defined. Computational Fluid Dynamics (CFD) techniques and codes were further refined to more accurately predict the aerodynamics and aerothermal environment, which address AFE geometry, air chemistry, viscous effects, hypersonic flight regime,

flow conditions during specific aerobraking maneuvers, real gas effects, and wake environment.

Advanced Systems Analysis

The Johnson Space Center has been a strong participant in the analyses of advanced systems and areas beyond the scope of the current Space Station plans. These efforts result in a review of technologies needed to support NASA's future advanced programs. Two major topics studied during the past year were the Transportation and Large Space Systems. In the area of transportation, two studies were performed to define the needed technologies to specify the next generation launch systems and to develop the new space initiatives. These studies are: (1) Design Goals and Technology Requirements for Future Launch Systems, and (2) Transportation Technologies Required for New Space Initiatives.

The Large Space Systems area was covered in the design activities of the Lunar Base Program. The Lunar Base Program is a bold, new U. S. space initiative to establish a self-sufficient lunar facility providing for permanent human habitation, intensive science, and export of lunar materials for use in space. To assist with the development of this initiative, the Advanced Programs Office of the JSC has assembled a NASA-sponsored study of the lunar base that draws on the resources of JSC, other NASA Centers, national laboratories, and the university community. This study is called the Lunar Base Systems Study (LBSS). The LBSS will create an engineered scenario for a manned lunar outpost. The final report will be both a "yardstick" by which other lunar base scenarios may be compared and a repository of pedigreed information that can be used to "flush out" other lunar base options. Substantial progress has already been made in some areas of this study.

Export of lunar materials for use in space.

Aeronautics and Space Technology

Significant Tasks

Chemical Heat Pump for Portable Life Support Systems

TM: Patricia A. Petete/EC2
Reference OAST 1

Efficient life support systems are necessary for future space exploration which will involve long duration manned missions where resources are commodities too valuable to expend. To meet this requirement, regenerable portable life support systems are being developed which eliminate the expenditure of resources such as water and oxygen.

In order to maintain thermal comfort during an extravehicular activity (EVA), it is necessary to dissipate the waste heat generated by the crewman and equipment in the portable life support system or extravehicular mobility unit (EMU). A metal hydride chemical heat pump (MHHP) is an innovative approach to accomplishing the transfer of waste heat without requiring either moving parts or electrical energy.

The MHHP concept is based on the heat of absorption and desorption of hydrogen into selected metal alloys. Absorption of hydrogen by these metal alloys is an exothermic reaction while desorption is an endothermic reaction. These metal hydride heat pumps have an inherently desirable characteristic in that they allow for system customization through the modification of the metal hydrides. By altering the hydride composition, the desired operating temperature range may be achieved. As shown by the example in the figure, heat would be removed from the liquid-cooled-garment water at 40° F by one alloy (hydride B) and rejected by the EMU radiator at 115° F by the other alloy (hydride A). This ability to alter the hydrides to accommodate system requirements also allows for higher heat-rejection temperatures than previously demonstrated with other thermal control systems. Thus, the radiator area can be minimized and the heat pumping is accomplished without creating excess waste heat.

A preliminary design of an MHHP incorporates lanthanum-nickel-tin and vanadium hydride as hydrides A and B, respectively. The MHHP consists of a tube-in-shell configuration for hydride B, hydride A tubes packaged within the radiator envelope, and associated valves for hydrogen and fluid management. The system design is being optimized to minimize complexity and maximize the hydride pumping characteristics.

Component hardware testing at NASA Johnson Space Center is scheduled for the middle of 1988 with potential for system level testing which would integrate the MHHP with other regenerable life support subsystems.

Metal hydride heat pump design concept.

TIME-SHARED RADIATOR

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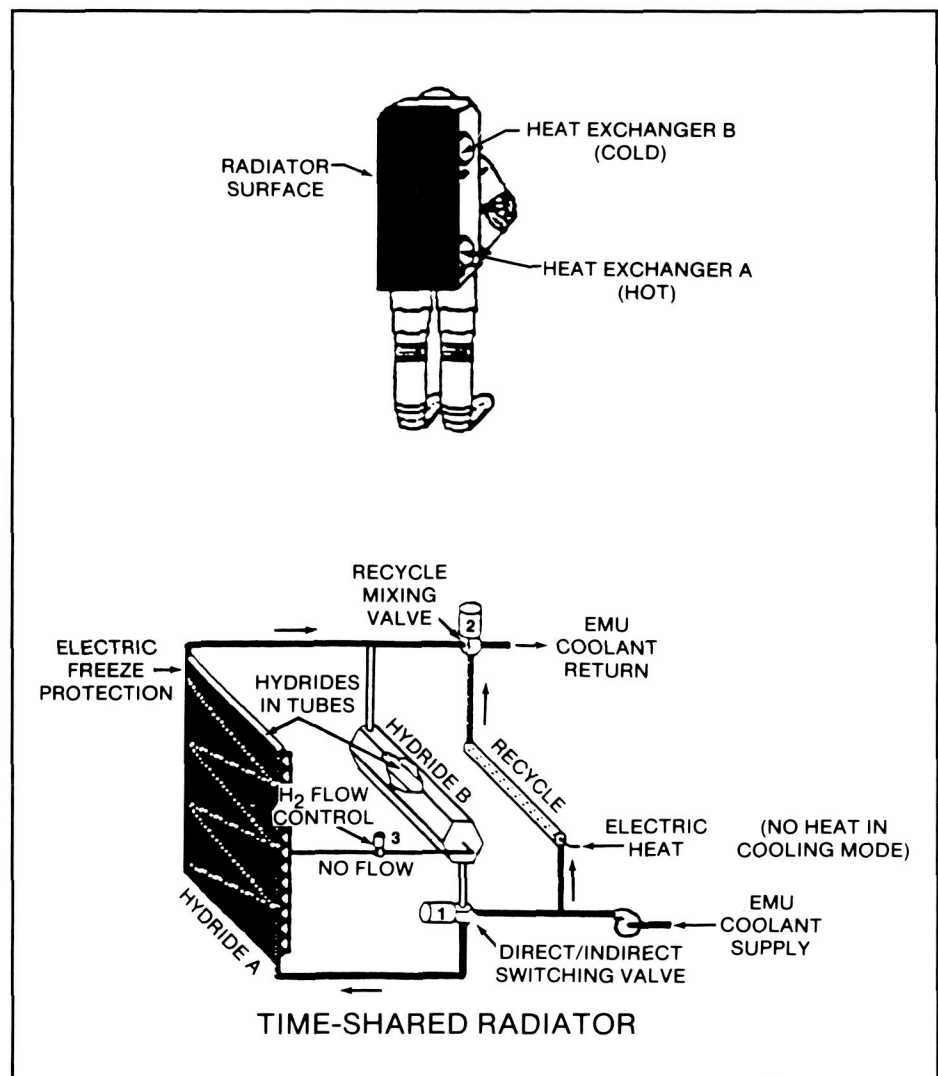
Two-Phase Thermal Management System Component Development

PI: Richard C. Parish/EC2
Reference OAST 2

The use of liquid and vapor phases of a thermal control working fluid for spacecraft thermal management has been studied by various NASA centers for several years. Recently, Space Station designers have baselined two-phase systems for heat acquisition and transport aboard the Space Station vehicle and associated free-flying platforms because of the obvious benefits these systems exhibit in reduced pumping power, system isothermality, and heat load flexibility. However, there have been uncertainties in the design process due to the limited amount of information available on liquid/vapor flow and heat transfer characteristics in a reduced-gravity environment.

To enhance the understanding of fluid behavior in a two-phase thermal management system (TPTMS) in a microgravity environment, an effort was initiated by NASA JSC to create a test stand which could be flown aboard the JSC KC-135 reduced-gravity aircraft , as well as being suitable for ground testing in JSC laboratory facilities. This test stand, shown in the figure, includes components of a candidate TPTMS, enabling measurement of pressure drop and thermal characteristics of the components and visualization (i.e., high-speed filming) and measurement of liquid/vapor flow phenomena. The test stand includes the basic components required of a two-phase transport loop such as evaporator, condenser, pump, accumulator, and pressure control valve.

The pump being used is a developmental pitot, phase-separation pump known as a Rotary Fluid Management Device (RFMD). This type of pump handles varying ratios of liquid/vapor mixtures, separating the liquid from the vapor, returning liquid to the evaporator for heat load acquisition and delivering vapor to the condenser for heat load rejection. Such a pump allows the use of flow-through evaporators and eliminates the need for active control of the liquid supply. The liquid/vapor mixture which exits the evaporator in the wet vapor return line was the focus of attention during ground and reduced-gravity testing, in April 1987, to assess various two-phase fluid flow phenomena.

High-speed filming and high resolution pressure drop measurements were accomplished in the 17-foot-long transparent line section to evaluate normal vs. reduced-gravity flow characteristics in the transport lines. Condensation of the thermal working fluid (Refrigerant-114) was also observed, filmed, and measured in an acrylic covered condenser section.

As a result of the comparative testing between the laboratrory and reduced-gravity aircraft environments, significant information was extracted concerning the operation of the TPTMS in an Earth-orbit environment. Only limited data exists on the effects of reduced gravity on liquid/vapor flow regimes, so the experiment has improved the data base significantly and provides confidence to the aerospace community on the utility of two-phase thermal management systems for future spacecraft.

TPTMS Test Stand.
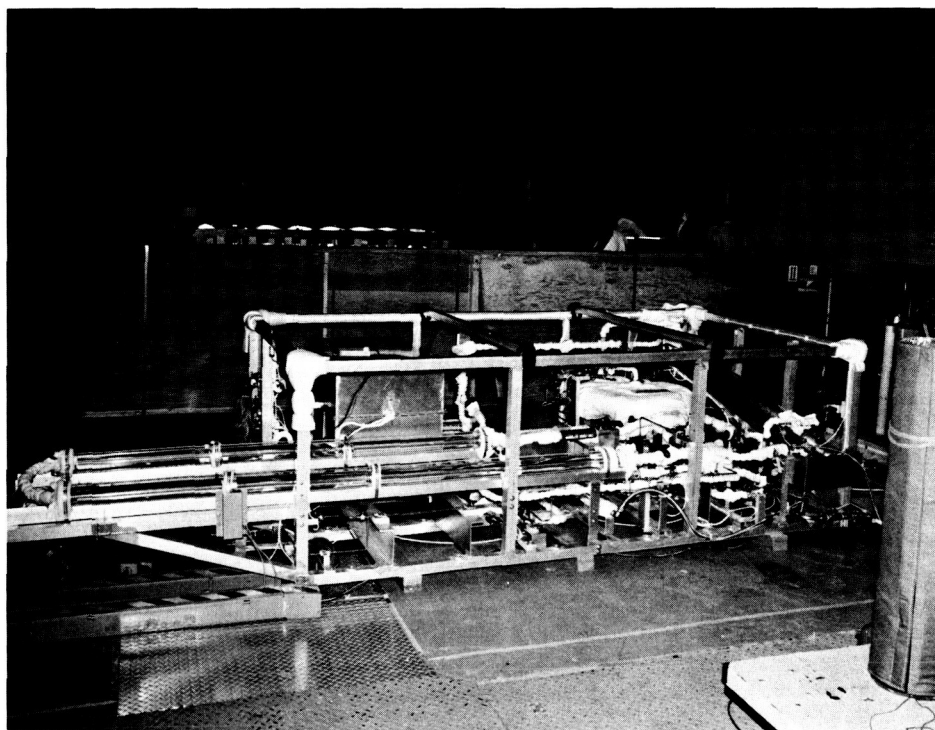
Supercritical Water Oxidation of Urine and Feces

PI: D. F. Price/EC5
Reference OAST 3

In the coming century, major NASA milestones will include a number of manned planetary expeditions and colonies. For most of these undertakings, total dependence on resupply of expendable materials from Earth is not feasible. The larger the amount of resupply required and the farther it must be sent from Earth, the more practical it becomes to reduce resupply dependency. Even for a low Earth orbit Space Station, reduction of resupply requirements is advantageous.

Supercritical water oxidation (SCWO) is one of the newer water recycling/waste treatment technologies being investigated by NASA. This technology is also being developed for terrestrial use as a method for destroying hazardous chemical wastes. One of the attractions of using SCWO in a space facility is its multipurpose capability. In addition to producing heated potable water, the process can treat feces and combustible trash, remove air trace contaminants, provide nitrogen for atmosphere makeup, and produce sterile nutrients for plant growth. The process could potentially be used to reduce the load on the humidity condenser and the carbon dioxide concentration subsystems.

SCWO is based upon the unique properties of water at conditions in excess of the critical point (374° C, 220 bar). Under these conditions, both organic liquids and the "permanent" gases such as oxygen and nitrogen are completely miscible with water. In combination with the elevated temperatures and pressures involved, it becomes practical to carry out rapid and complete oxidation in an aqueous medium. In addition, SCWO allows an efficient separation of heteroatoms, which precipitate as salts or oxides from the low density process stream. Feeds containing sulfur, halogens, phosphorus, or carbonates will, with appropriate cations, produce an ash containing sulfates, halide salts, phosphates, and carbonates. Heavy metals, with the exception of mercury, are precipitated from the supercritical water stream as oxides or oxy-anions. Nitrogen passes through the system as an inert, while feed nitrogen is converted to either N_2 or harmless nitrous oxide (N_2O). These features make SCWO a promising method of producing potable water from an aqueous waste stream.

Prior work indicated that aqueous solutions of urea and urea plus sodium chloride could be effectively oxidized by the SCWO process, with essentially complete conversion of carbon to carbon dioxide and nitrogen to N_2 and N_2O gas. The objective of the current experimental work was to demonstrate the basic applicability of the SCWO process to human urine and feces waste. Attainment of this goal required modification and upgrading of the bench scale SCWO unit developed by Modar Inc., Natick, Massachusetts, to allow more continuous operation. Once satisfactory system operation was achieved, experiments were conducted to demonstrate organic carbon destruction, organic and ammonia nitrogen conversion, ash separation, and gas and liquid effluent quality. Five experimental runs were conducted with feed solutions consisting of urine solids and ethanol in water, feces solids in water, feces and urine, and feces/wipes in urine. The feces/wipe feeds were taken from postflight samples from the Shuttle Orbiter commode. Results of these experiments showed essentially complete conversion of organic carbon to CO_2 or char, of organic nitrogen to N_2 or N_2O, and efficient removal of all major heteroatoms (sodium, phosphorous, chlorine, sulfur, potassium, calcium, and magnesium) as ash. Process product water would probably require ion exchange or other suitable polishing to remove residual heteroatoms in the low ppm range.

Continuous collection and removal of process ash remains a problem. Continued research is planned to characterize ash formation and to evaluate effects of ash removal techniques upon reactor design.

MODAR bench scale SCWO unit.
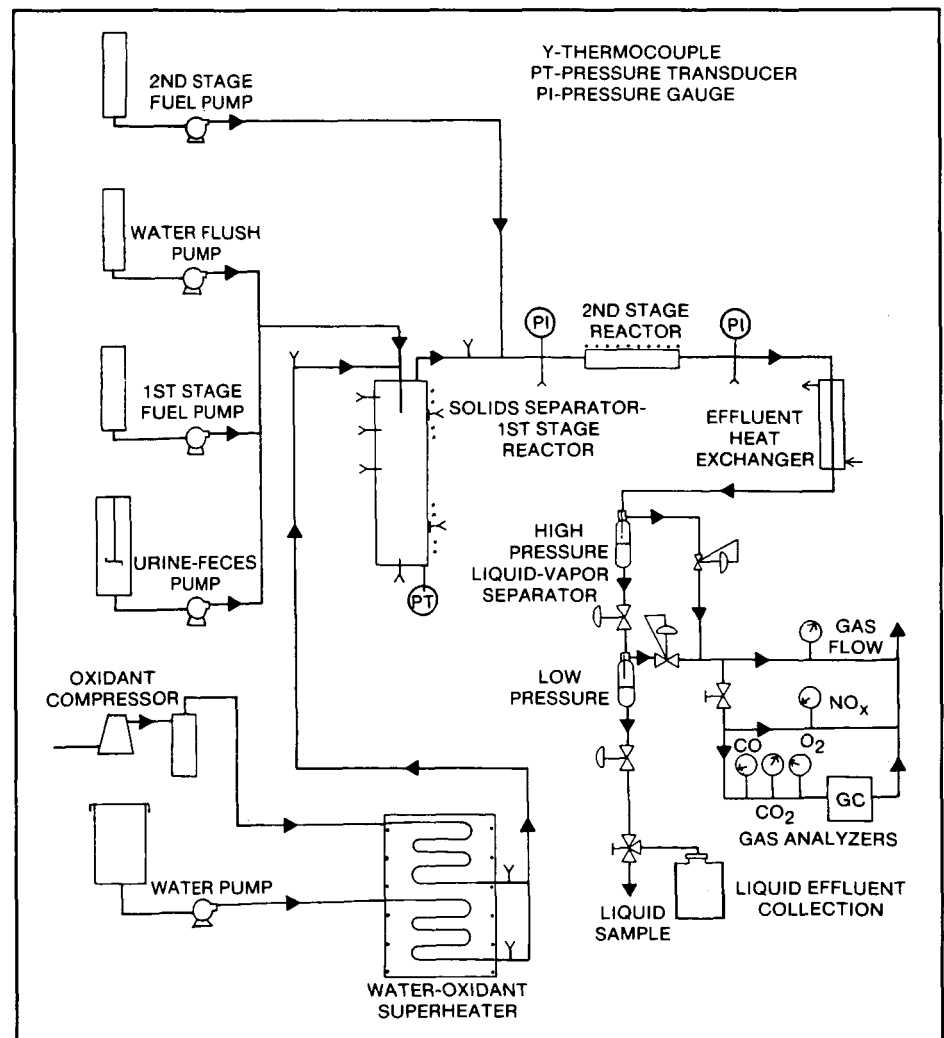
Space Station Materials Evaluation Studies

TM: J. T. Visentine/ES5
Reference OAST 4

In cooperation with the Johnson Space Center, a high energy (2-5 eV) atomic oxygen source has been developed by the Los Alamos National Laboratory. This source produces a well-colimated, translationally hot beam of oxygen atoms for use in studies involving etching and glow mechanisms of spacecraft surfaces and for full-life certification of surface coatings for Space Station that are resistant to O-atom attack. This facility utilizes a technique known as laser-sustained continuous optical discharge to produce neutral, ground-state atomic oxygen at flux levels sufficiently high (10^{16} to 10^{17} atoms/S·cm^2) to enable Space Station materials and coating concepts to be evaluated for full-life performance (20 to 30 yrs.) within reasonable periods (50 to 60 hrs.) of time.

Initial checkout of the facility has been completed, and studies are underway to characterize the beam in terms of its composition and purity, its monochromaticity, O-atom flux density, and translational energy. Recently, fluxes as high as 6×10^{16} atoms/S·cm^2 and energies in the range of 2 to 3 eV have been achieved using oxygen-neon mixtures to produce the oxygen beam. Laboratory exposure studies using silver and Kapton films have demonstrated that this facility is capable of accurately simulating the STS flight environment in terms of recession rates, increases in oxide thickness, and surface morphology changes. The beam energies have been limited by boundary layer cooling effects which occur as the plasma is placed within the nozzle orifice. It is anticipated that energies characteristic of the orbital environment (5 eV) will soon be achieved by increasing the nozzle diameter to reduce the amount of boundary layer cooling and by using oxygen-helium mixtures to accelerate the oxygen to higher velocities.

Sputtered Teflon films are currently being evaluated using O-atom silver actinometers to detect the end point of reaction. Initial results have shown the laboratory exposure produces lower reactivities for Teflon than for Kapton, but the measure values are higher than those obtained from the STS-8 mission. These discrepancies may be due to sputtered Teflon yielding higher reaction rates than commercially prepared Teflon films, or to difficulties in obtaining accurate mass loss measurements for the STS-8 specimens as a result of the limited (3.5 × 10^{20} atoms/cm^2) atomic oxygen exposure and errors inherent in using commercial microbalances to obtain the weight-loss measurements.

Future activities to be accomplished by the laboratory include providing a closed-loop cooling system for the high-temperature expansion nozzle which will accommodate the higher temperatures produced by the oxygen-helium plasma discharge; initiation of Space Station engineering studies to investigate the performance of sputter-deposited Al$_2$O$_3$ and SiO$_2$/Teflon films for atomic oxygen protection of thermal control surfaces and large-area, flexible solar arrays, respectively; and calibration of the ion-neutral mass spectrometer provided by the Air Force Geophysics Laboratory for the EOIM-3 flight experiment.
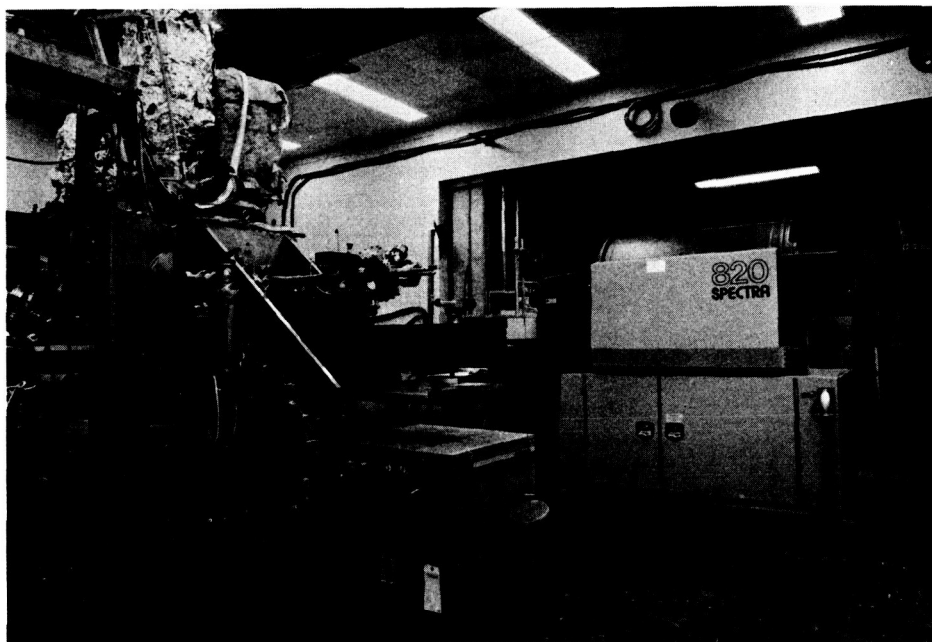
Atomic oxygen simulation facility for Space Station material evaluation studies. The high intensity (1,500 W), continuous wave carbon dioxide laser is shown to the right of the exposure chamber.

Alignment system, showing the optical paths of the two high-intensity laser beams. The pulsed laser is used to initiate the plasma, which is then sustained using the continuous wave (cw) infrared laser.

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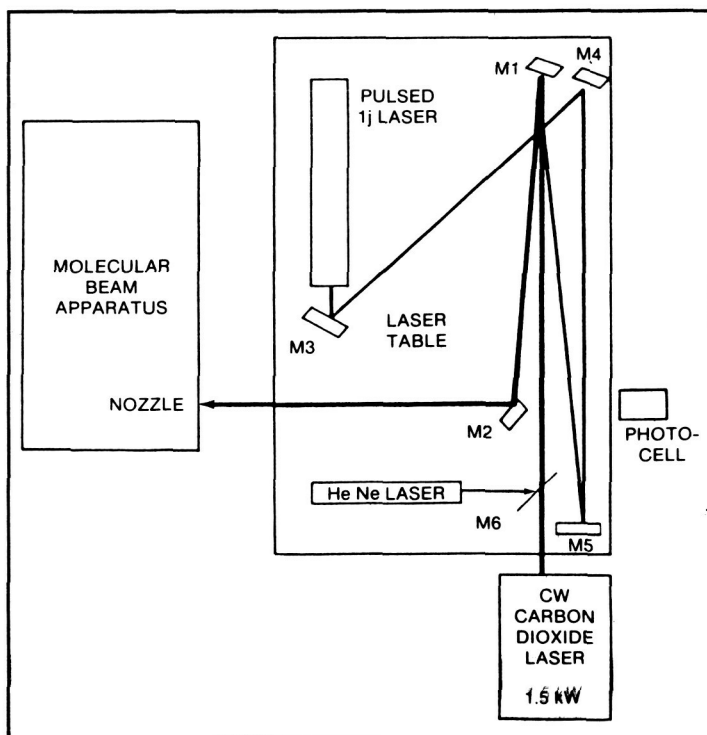
Testing and Analysis of the Department of Defense Ada Language

TM: Stephen Gorman/FR12
Reference OAST 5

In 1988, at the request of NASA OAST, the project-related resources of the successful Joint NASA JSC University of Houston at Clear Lake (UH CL) APSE Beta Test Site team were officially transitioned into what is intended to be a permanent NASA research resource, the Software Engineering Research Center (SERC). SERC at UH CL plans to investigate software engineering research issues which are critical to NASA's future. The focusing question for the research is: "How can software systems be engineered for life cycle support of large, complex, distributed systems with non-stop components and with life, property, and mission at stake?" A part of the mission of SERC, therefore, is to help advance the edge-of-knowledge from the current status of programming-in-the-large to software-engineering-in-the-large. This includes the investigation of interface issues to all related computer systems and software engineering activities in the life cycle of large, complex, distributed applications: software engineering and the life cycle support environment; computer systems engineering, hardware engineering, and operations and logistics. As shown in the figure, this perspective is applied across host, integration, and target environments. This work begins by addressing the theoretical foundations of both the technical and management issues of software engineering. In addition, test bed projects will be used to demonstrate proof-of-concept and support empirical investigation. Two levels of research commitment for critical issues were defined: presence and leadership. Presence implies tracking and participation at the cutting edge. Leadership implies a primary responsibility for advancing the cutting edge. Considerations of criticality or uniqueness to NASA, timeliness of needed advancements, required and available resources, likelihood of timely advancement being made by other researchers, and other criteria are used to determine which of the two levels is appropriate for each critical issue to be addressed.

As a complement to SERC, a sister organization called the Software Engineering Professional Education Center (SEPEC) was created to address education and training issues associated with SERC research. Together, SERC and SEPEC initiated the process of formal affiliation with the Software Engineering Institute (SEI). Attendance and participation in SEI activities have already been initiated and final signatures and a joint press release are anticipated early in 1988.

Some of the activities which were initiated during the beta test site project and are continuing as SERC activities include the following. SERC is committed to sustaining a role of international leadership in two Ada-based activities: (1) run time support environments and (2) extending CAIS conforming Minimal tool sets of Ada programming support environment (MAPSE's) into full APSE's. The first activity is being coordinated with the Catalog of Interface Features and Option (CIFO) subgroup of the Ada Run Time Environment Working Group (ARTEWG). The second activity is being coordinated with the Software Support Environment Team of the Space Station Program. SERC is also committed to sustaining a presence role in such activities as evolving the Common APSE Interface Set (CAIS); evolving the 2167/2168/SMAP Standards for life cycle documentation and quality management; evolving the IRDS Standard as a common systems modeling tool for semantic representations in Entity Attribute/Relationship Attribute (EA/RA) form; evolving standards for Common Interface Sets among subsystems of network communication services, network information services, network application services, and network configuration control services; plus a continuing presence in international professional meetings and conferences related to research and education in the Ada culture of software engineering.

During 1988, twenty formal research tasks were initiated or conducted by SERC. Sixteen of these are at the presence level. Examples include an Ada-based state-of-the-art expert system builder, the benchmarking of Ada on embedded computer systems, the testing and verification of critical flight software for embedded computers, and an Ada resources data base. Four tasks are at the leadership level. Examples include a model for distributed Ada entities, proof-of-concept for instrumenting Ada run time support environments, a model for computer systems and software safety in distributed applications, and life cycle reusability.

It is anticipated that in 1988, at least a presence will be sustained in most of the research areas addressed during the SERC's first year of operation. In addition, if funding permits, work in all areas with a current leadership role will be accelerated and integrated through three principal research initiatives. A common theme of all three initiatives is the simultaneous support of mission and safety critical requirements in large, complex, distributed systems with non-stop components. The first initiative focuses on creating a fully instrumented, highly reconfigurable test bed to support empirical research in the creation of a Portable Common Execution Environment (PCEE). The second initiative focuses upon the extension of APSE's to include an integrated Computer Aided Software Engineering (CASE) capability to address the development and sustaining of mission and safety critical components. The third initiative focuses on a life cycle approach to reusability integrated across host, target, and integration environments for the support of mission and safety critical components.

Three types of environments addressed by software engineering.

HOST ENVIRONMENT
(SHOWN AS DISTRIBUTED)
- DEVELOP
- SUSTAIN

INTEGRATION
ENVIRONMENT
- MONITOR &
  SUSTAIN
  CURRENT
  BASELINE
- CONTROL
  INTEGRATION
  & EVOLUTION
- SUPPORT
  EMERGENCY
  INTERACTIONS

TARGET
ENVIRONMENT
- DEPLOY
- OPERATE
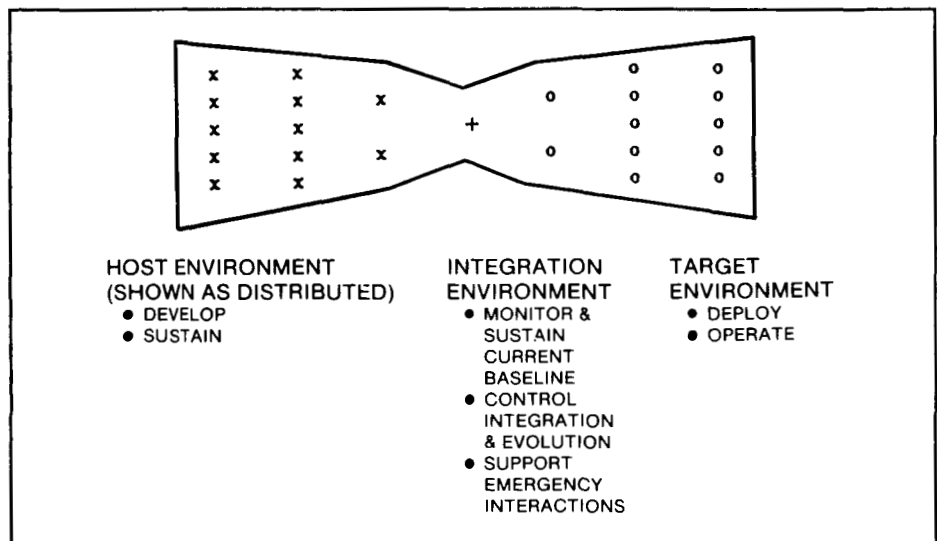
Guidance, Navigation, and Control Systems Management and Partitioning

TM: A. E. Brandli/EH3
Reference OAST 6

In this research, the Guidance, Navigation, and Control (GN&C) system architectures, system management techniques, and maintenance concepts to satisfy an integrated set of performance requirements and mission objectives are addressed. The overall thrust is to achieve enhanced reliability, performance, and cost-effectiveness by identifying and demonstrating viable GN&C system architectures. Results from this study are applicable to Space Station, the Crew Emergency Return Vehicle (CERV), and other NASA missions and programs. Two areas of study were the GN&C system interface with the Facility Management System (FMS) and partitioning methods of GN&C functions among distributed processors.

For increased efficiency and reliability, it is important to address the need for coordination of the GN&C System design with a FMS design. The objective is to define criteria for partitioning GN&C functions between the GN&C and FMS hardware/software elements. These criteria will provide the decision mechanism for determining which functions are performed under the GN&C system executive, facility management executive, or crew control where applicable. An example of GN&C/FMS interactions are the FMS control functions for test capability needed to support maintenance and troubleshooting tasks. To provide background information, the DOD approaches to avionics maintenance are being investigated, and literature indicated expert systems are being developed as offshoots of existing automated test equipment. Speedy, unambiguous, and accurate diagnostics are key DOD requirements for automated avionics maintenance, and those same requirements will have even greater significance for avionics resident on Space Station.

The second area under this research is concentrated on improving the methodologies used to partition GN&C functions among distributed processors (e.g., global, regional, local). Improved methods must produce a subsystem design with greater emphasis on the subsequent system integration, verification, and on-orbit maintenance.

A major issue associated with functional partitioning for modern distributed avionics systems is the bus traffic between the computational elements. For Space Station, the GN&C interfaces with several other systems during remote piloting tasks. To further define the problem, we have initiated a study activity to define the time-critical interfaces, the parameter types, and the rates of data interchange.

In the aircraft industry, avionics development has placed an emphasis on embedding software within sensors and effectors. For example, this approach provides a buffer between the built-in test equipment and the core avionics flight software. Industry experience shows that test equipment changes significantly during the aircraft design and development phases, and separation of those embedded functions from the core software results in significant savings in overall software life-cycle costs. Other examples have been found where smart actuators (embedded processors) are being utilized which can receive and respond to commands direct from the pilot control stick in the event of a core flight computer failure. The embedded processor in this application is providing a backup mode or added fault tolerance to the system architecture. Investigations were also conducted to determine the partitioning approaches being applied to new unmanned spacecraft.

A more formal method for partitioning software was formulated and demonstrated in a limited Space Station application. The method is based on a set of pre-established objectives and constraints. Specific software processes for the system being designed are defined, and the system objectives are implemented in a prioritized order. The formal procedure causes software functions to collect into groups commonly called subsystems. Varying the order of priority for objectives will lead to different subsystem configurations. Constraints are applied last, and objectives are compromised where necessary to meet the constraints. Using this approach, traceability between subsystems and functions is ensured, justification for a resulting design is concise and reviewable, and a clear audit trail is available for future system updates and design modifications. A graphical representation of the part 2 study activity is shown in the figure.

GN&C/DMS architecture trades on processing levels.
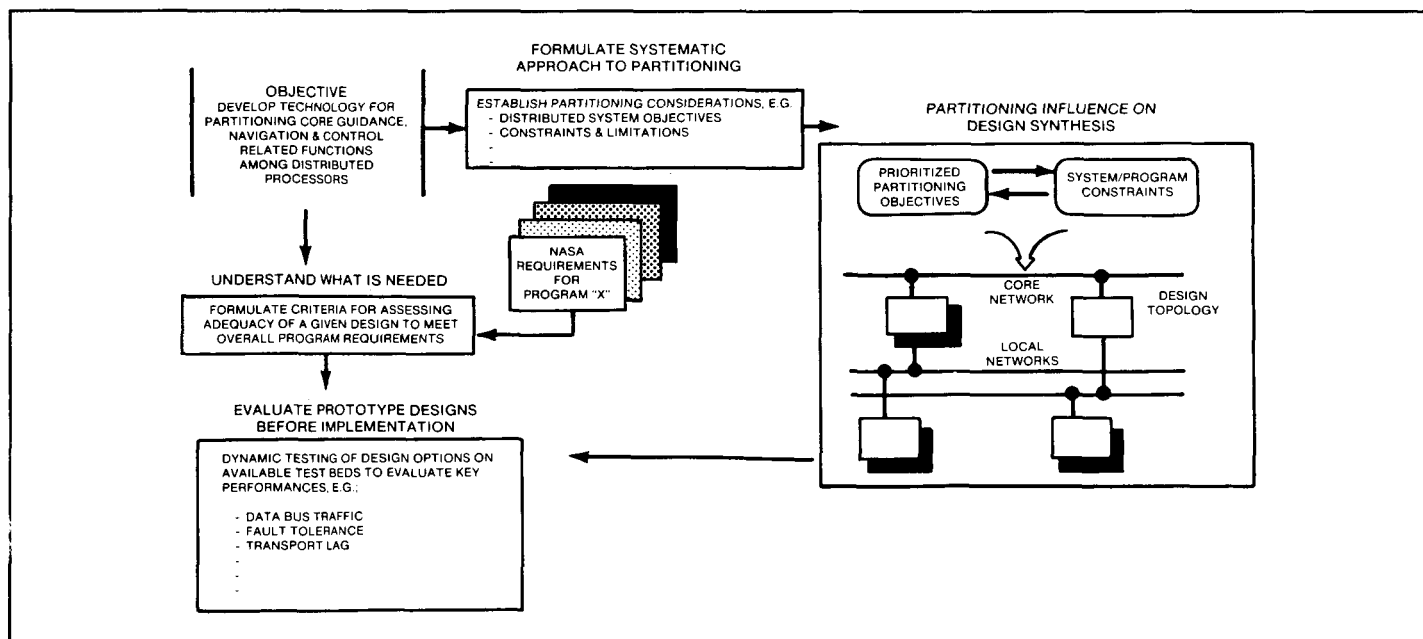
Space Station Adaptive Control for Deployment and Operations

PI: Lynda R. Bishop/EH2
Reference OAST 7

Unique Space Station characteristics such as its large, partially asymmetric configuration, incremental buildup, time-varying mass properties during operations, and dissimilar control effectors (e.g., control moment gyros and reaction control jets) require that application of adaptive control techniques be studied at an early stage in program development. Unique Orbital Transfer Vehicle (OTV) characteristics such as its time-varying mass properties during operations (and the fact that the OTV may carry large objects with unknown mass properties) may also require utilization of similar advanced adaptive control technology for attitude control. There is no precedent for control of a space vehicle with these characteristics, and it appears likely that utilization of advanced adaptive control technology will be required. Although there have been some limited studies of adaptive control designs for the Space Shuttle, no in-depth system analyses for application of the concept to large, manned space vehicles or to vehicles with radically changing mass properties have yet been performed. Potential benefits of an adaptive control system would include significantly reduced control effector size, weight, and/or propellant requirements as well as enhanced capability to adjust to failures on orbit.

A control system has been developed for Space Station which provides a higher degree of adaptability to changes in vehicle configuration and effector failures and which has the capability to automatically detect and identify these changes and failures, providing an autonomous self-adaptvie capability.

A mass-properties identification algorithm has been developed to detect changes in vehicle configuration and determine values for vehicle mass properties. This algorithm works by comparing vehicle response measured by rate gyros and accelerometers to control effects of either reaction jet firings or control moment gyros. Starting with no prior mass properties information, this algorithm has been shown to converge to better than one percent accuracy in vehicle inertia matrix values and a fraction of an inch in center of gravity location as well as approximately one percent in mass for the Shuttle Orbiter. In addition, this algorithm can measure variations in jet thrust levels down to a fraction of a percent.

An advanced control capability has been built to control spacecraft with changing mass properties and effector capabilities as determined by the identification system described above. This control system has a high degree of fault tolerance and a substantial capacity to adapt to mass properties changes. Flight control can be performed by either reaction control jets, control moment gyros (either single or dual gimballed), or by combinations of effectors. Limitations and singularities of the control effectors are taken into account, and the system can be made fuel optimal by parameter changes or biased to favor some subset of effectors.

The identification and control algorithms have been combined into a system which is capable of performing control of a changing spacecraft, recognizing those changes, and adapting to them without outside intervention. Simulation results to date indicate that nearly all control/adaptability objectives have been met. Flight demonstrations of the mass properties identification technique are in planning, and the usefulness of this system to other spacecraft is under evaluation.

Space Station adaptive control for deployment and operations.
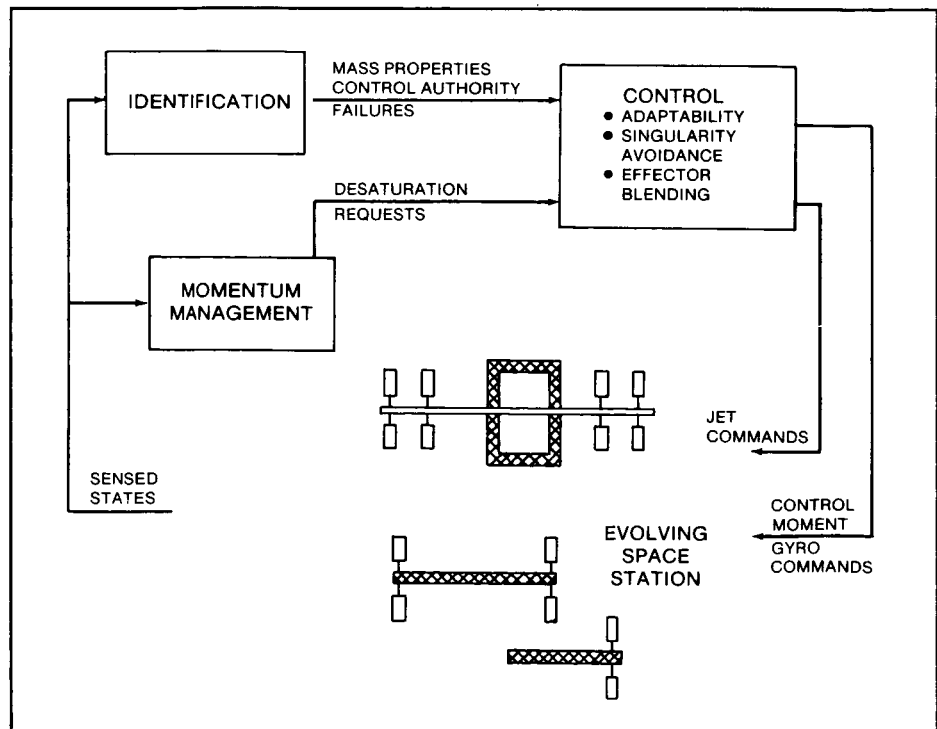
AIPS Hardware for the Data Management System Laboratory

TM: L. W. McFadin/EH6
Reference OAST 8

Space and other uses of computers require varying degrees of reliability to satisfy operational and safety requirements. Examples are digital flight controls for aircraft that require extreme reliability and control systems for Space Station which require accurate detection of computer failures and safe responses to those failures. Systems designed for applications today are, by and large, custom tailored for specific applications. These system designs often include unique architectures, ad hoc solutions for fault tolerance, and nonstandard or highly customized software and operating environments. Substantial expense is incurred not just in the unique design but also in the validation and maintenance over the system's life.

The advanced Information Processing System (AIPS) is an ongoing NASA technology program, the principal goal of which is to produce a generic fault tolerant system architecture suitable for a broad range of space and Earth applications. This generic architecture is to be translated into specific validated building blocks and system development tools to aid system synthesis and validation. One of the AIPS building blocks, the Fault-Tolerant Processor (FTP), provides redundancy that may be either duplex, triplex, or quadruplex. The FTP includes systems software that provides for the management of redundancy independent of the application and "operating system services" required for application execution. The application may be developed as for a nonredundant computer, using only the operating system's standard services. The building block and development tool concept provides the potential to reduce the proliferation of system architectures and to reduce costs associated with a system's life cycle.

The Charles Stark Draper Laboratory is developing an instantiation of the AIPS FTP for use in the Data Management Systems (DMS) Test Bed at the Johnson Space Center. The FTP has incorporated changes to enhance performance and to provide additional support for a test bed environment. The AIPS FTP uses a Motorola 68010 processor which has been replaced by a Motorola 68020 processor and Motorola 68881 math coprocessor. The processor clock operating speed has been increased to 16 mHz. As the FTP and its system software provide a means to embed applications directly from the nonredundant computer environment, integration of prototypes and/or actual application may be speedily accomplished.

The FTP operating within the DMS Test Bed will provide a fault-tolerant computing facility for application, rapid prototyping, and demonstrations. This will prove to be of great value in the validation of system and software requirements for future applications, in that effectiveness of system design attributes and difficulty of implementation (cost) may be better gauged through the prototyping process.

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Fault-Tolerant Processor laboratory hardware under testing.
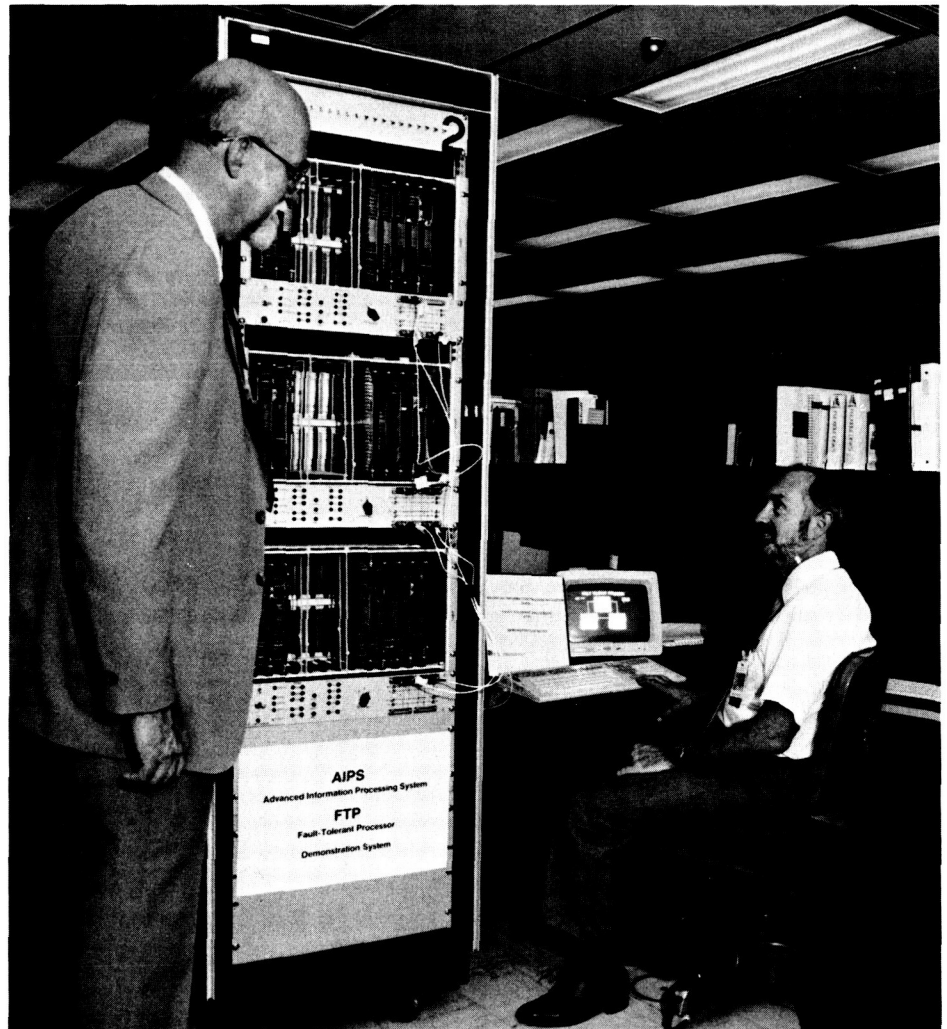
Crew Station Human Factors: Human-Computer Interaction Laboratory

PI: Marianne Rudisill/SP3
Reference OAST 9

The purpose of the Johnson Space Center Human-Computer Interaction Laboratory (HCIL) is to examine the user interaction with advanced display, control, and computer technologies. The laboratory provides a facility for the rapid prototyping and evaluation of several types of human-computer interfaces. Additionally, the facility has the capability for automated data recording at a detailed level of human-system interaction. The project involves performing studies examining user interaction with these technologies, with particular emphasis on their application to operations within the space environment. Controlled evaluations are conducted, objective human performance data are collected and analyzed, and results are detailed in technical reports with recommendations concerning how these technologies may be incorporated into spacecraft workstations to optimize the user/system interface. For example, results from each of these experiments and evaluations are incorporated into the design of the Space Station. Additionally, HCIL personnel are responsible for the design of the Space Station Information System's Human-Computer interface and accompanying Guide, and are monitoring the design of the Workstation System.

Several experiments were conducted during the past year in the HCIL, and several new research paths have been started. A brief description of each follows.

Electronic display of procedural information: Two experiments were performed to examine user interaction with electronically-displayed procedures. Users were required to follow a series of procedure steps, displayed within a screen window, to determine the malfunction in a simulated Shuttle system. The number of steps displayed at one time was limited to seven. The first experiment manipulated the positioning of these steps within the display window such that the user saw the current procedure step (1) with steps just completed, (2) with upcoming steps, or (3) with some completed and some upcoming steps. In the second experiment, graphics-based and text-based display modes of procedures were compared. Subjects were found to be fastest when viewing upcoming procedure steps; subjects were more accurate and faster when procedures were graphically displayed. These results indicate that electronically-displayed procedures will be most effective when displayed graphically. If textually displayed, the most effective format is one that shows upcoming procedure steps.

Hypertext: An evaluation of hypertext systems was completed. Hypertext systems provide a method for structuring a data base as a relational network in which the network nodes are the concepts in the data base and the relational links provide a means of moving between concepts; accordingly, hypertext is especially well-suited for displaying procedural information. A specific, IBM PC-based hypertext system, Houdini, was assessed. A demonstration of the application of hypertext to space tasks is planned, enabling guidelines for its use on spacecraft to be developed.

Multifunctional controls: A study of a multifunctional control system, Programmable Display Pushbuttons, indicated important limitations in its use in complex tasks for spacecraft operations. The study showed that multifunctional devices will be most effective when used in conjunction with a computer screen to maintain a historical record of user selections. A demonstration of the use of multifunctional controls for space tasks is being planned.

User interaction with graphics: Two experiments were conducted to examine users' interactions with graphical elements. In the experiments, users' perceptual and functional categorizations of statistical graphs and iconic symbols, respectively, were examined. The data, presently being analyzed, will provide information about how users group graphical stimuli. This information will be used in the subsequent design of graphical displays.

The results of the above experiments and of experiments currently being planned or conducted will be integrated into the User-Computer Interface Guidelines and Requirements for future spacecraft user interface design. This will result in increased safety and productivity of the crew, through decreasing the probability of errors and increasing the ease with which a procedure is performed.
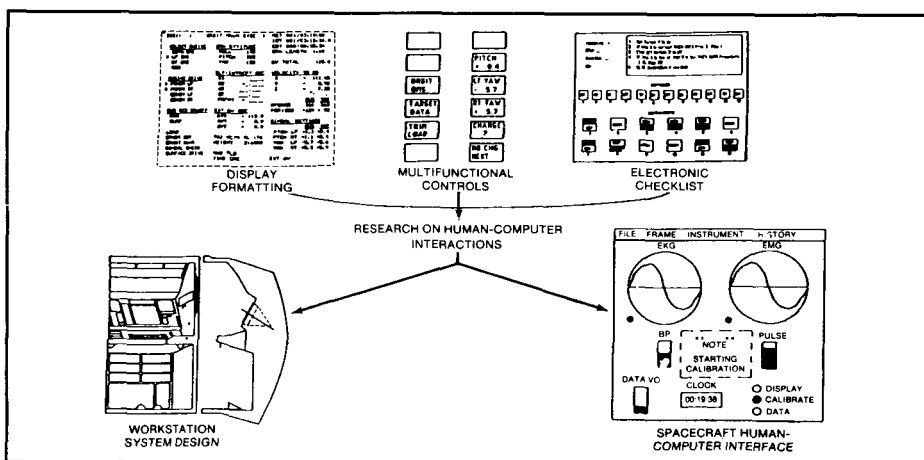
The JSC Human-Computer Interaction Laboratory examines human interaction with advanced computer technologies and incorporates research findings into spacecraft workstation and HCI designs.
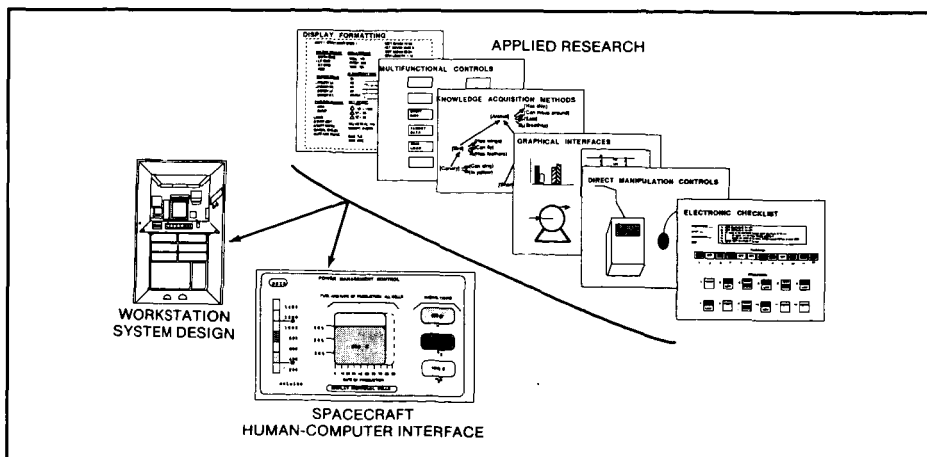
EVA Helmet-Mounted Display

PI: B. J. Woolford/SP34
Reference OAST 10

During extravehicular activities (EVA), an astronaut may perform tasks ranging from a well-rehearsed contingency operation to an improvised procedure for securing or repairing a satellite. The astronaut currently relies on specific training and on cue cards worn as a cuff-mounted checklist. The only real time updates possible are through verbal queries and answers over the radio.

For Space Station, EVA's will become even more varied and intensive than they already are. Unforeseen situations will arise for which the crew will not have preprinted instructions. Furthermore, the length of time and the awkwardness of flipping pages in a checklist, the interference with the job caused by keeping the arm in a position where the checklist is visible, and the variations in view necessitated by looking down at the cuff then back at the task all impose high costs on performing an EVA and can impact safety considerations for the mission.

The Crew and Thermal Systems Division of Johnson Space Center has initiated development of two prototype helmet-mounted displays (HMD's) which will interface with a suit computer and radio link and will permit display of the task instructions in the upper area of the helmet itself. The HMD will be controlled by a voice command system. The combination of display in the normal field of view and voice command will permit hands-free operation of the display. Through the radio link to the computer, new procedures can be uplinked from the ground, and detailed images can be forwarded from the spacecraft to the EVA astronaut. This will provide greater flexibility and enhanced productivity in performing EVA tasks.

The Man-Systems Division has been funded by OAST to design the human interface for this system. Display format and command logic for the control system are being studied. In particular, the sequence of commands in the voice controller are being analyzed in great detail to balance naturalness of commands with good recognition characteristics by the speech analyzer. Also, the ease of movement through the menus and speed of access of any function must be balanced against complexity and display density of the menus. Since EVA's can last for up to eight hours, and fatigue may change the characteristics of the voice over that time, a technique for updating the voice templates through voice commands is being tested.

Specifications and requirements for two prototypes have been written, and contracts are under way to build the prototypes. The first, a CRT system, has been received and is undergoing in-house evaluation. To simulate the helmet mounting, two glass panels are suspended from a head mount. The displays are shown in the upper part of the field of view, and the wearer can look through the display to see the outside world simultaneously. The second prototype, based on a liquid crystal display, will be completed this summer. Both will be evaluated on several criteria, ranging from power consumption to resolution and contrast. The work on the voice command system is independent of the display model selected for in-flight testing. This study will result in a human-factored design of the HMD. The overall effect will be to increase the safety and productivity of crew members during EVA.
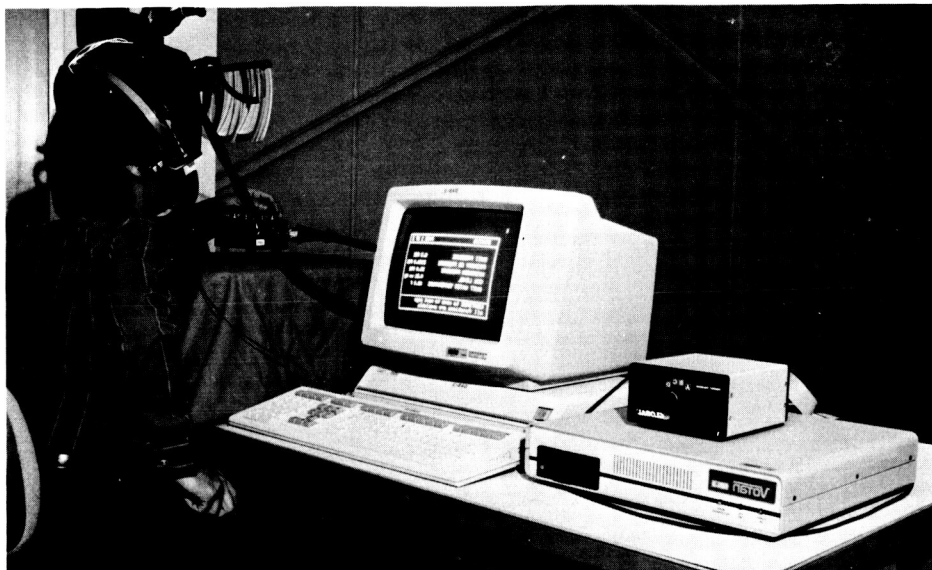
The voice analyzer and a CRT controlling the computers are used in evaluating the prototype helmet-mounted display.

Seen from above, the helmet-mounted display prototype consists of two CRT's fed by a computer and an optics assembly that projects the CRT screen image onto the face mask.

Artificial Intelligence-Human Interface with Expert and Planning Systems

PI: Jane T. Malin/EF5
Reference OAST 11

Future spacecraft, including the Space Station, will have intelligent software that processes sensor data, analyzes malfunctions, and provides the astronaut with assistance in operating and troubleshooting the subsystems. These programs will be based on models of physical processes occuring in the subsystem. To communicate effectively with the human, the software must be designed to use models compatible with the operator's thought processes and underlying models. System schematics and related graphics and diagrams are commonly used to describe and analyze physical systems. This research project is directed at optimizing the communication between intelligent software and the operator through studying the human's models and the most effective techniques for presenting information.

A cognitive theory of diagram comprehension has been developed for tasks in managing engineered systems, and guidelines for diagrammatic displays of engineered systems have been formulated. Studies are being conducted of alternative diagram formats to test the theory and provide a basis for refining the guidelines.

The studies indicate that diagnosis of malfunctions is aided by dynamic diagrams that show the topology, causal pathways, and internal states of system components. Future experiments will use diagrams of a device in a Space Station subsystem and will investigate how various types of diagrammatic information help the operator infer or verify malfunctions.

Qualitative models of electrical and thermal systems are being developed to support development of standardized model libraries for intelligent software systems. Fluids have been modeled as molecular collections in order to reason about thermodynamic properties. Mixtures of device-centered and process-centered models of systems are being studied. Concepts of the role of qualitative models in several phases of intelligent computer aided engineering and operation have been developed to provide a context for the theoretical work. Future work will include developing fault models and exploring mixtures of qualitative and quantitative representation. The work will culminate in building prototype qualitative models of elements of Space Station subsystems.

Common sense system models used by engineers in failure management have been analyzed. The models used by engineers for developing failure management systems are primarily qualitative and are tailored to support the predictive analyses needed to support rule development. These models represent critical assumptions underlying the rules and procedures of failure management systems, and developers and operators need access to them when revising rules or designing alternative procedures in novel failure situations. A paper describing the results of this analysis is in press in an IEEE journal. Issues in using dynamic system schematics for presenting system failure information and underlying models are being identified while developing a prototype qualitative modeling tool for use in intelligent failure management systems. A paper on this prototype modeling tool was presented at the national conference of the American Association for Artificial Intelligence.

Work has begun on developing software to support integrated development of model-based intelligent management software and diagrammatic interfaces. Man-machine communication tasks are being analyzed in the context of Space Station intelligent systems. Next year, prototypes will be built of expert systems with diagrammatic interfaces for space operations scenarios. These prototypes will illustrate how graphical displays should be designed to aid development and operation of intelligent systems for failure management. Methodology and tools for designing graphical interfaces for intelligent systems will also be prototyped.

Animated schematics are used to present system failure information in the CONFIG prototype qualitative modeling tool.
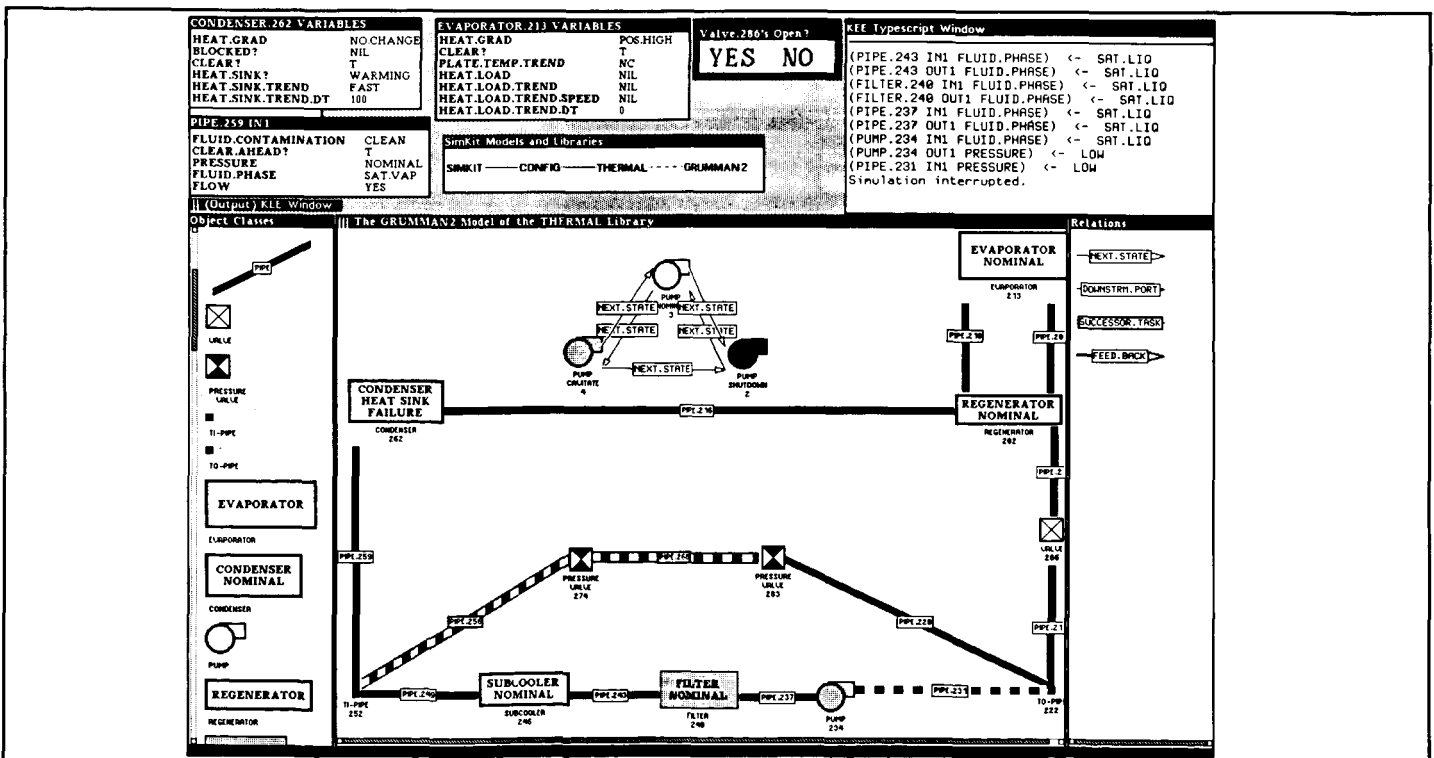
Tailorable Advanced Blanket Insulation

TM: R. Richard/EX3
Reference OAST 12

Thermal Protection Systems (TPS's) provide the means by which structural and interior temperatures of space vehicles are held to safe levels when interacting with Earth's atmosphere. The varieties of TPS used are selected on the basis of anticipated heat loads and the maximum predicted temperature at a given location. The major component of the heat shield as applied to the Space Shuttle is rigid tiles. However, a significant quantity of flexible heat shield material is used. The design and selection of TPS materials has a tremendous impact on overall system weight and cost. Flexible materials have several advantages over rigid materials in their ability to conform to curved surfaces, to cover more surface area per unit installation, and to allow for on-the-spot tailoring of materials to cover uniquely shaped areas in a timely fashion. A major disadvantage of the flexible TPS materials is that their temperature and heat input tolerance is usually lower than that for the rigid materials.

Because of the advantages of the flexible TPS materials, effort has been expended in developing materials and fabrics that would possess a greater heat input capability and tolerance to temperature extremes. One result of the TPS research effort is the development of a silicon carbide fiber which has been designated Nicalon. A weaving process has also been developed that permits the manufacture of a 3-dimensional fluted weave fabric that can be filled with thermally enhancing substances, such as amorphous silica, or aluminoborosilicate (trade name Nextel), or other materials capable of withstanding high temperatures. When used with this combination of materials and manufacturing techniques, the resultant TPS fabric is designated Tailorable Advanced Blanket Insulation (TABI).

The TABI development effort is managed by the Lyndon B. Johnson Space Center (JSC), through the research and technology (R&T) programs funded by the Office of Aeronautics and Space Technology (OAST). The major technical direction is provided by personnel of the Ames Research Center (ARC). JSC provides the overall integration management and program planning support of the National Transportation System (NSTS) Orbiter Experiments (OEX) Program.

Prototype TABI material was received at ARC for evaluation in June 1983. Since that time, a Preliminary Design Review (PDR) was held in February 1986 and a Critical Design Review (CDR) was held in August 1987. Future activity on TABI development awaits decisions related to completion of certification tests at considerable expense or in-place flight testing on OV-102, assuming that "fail-safe" status is achieved.

The TABI as presently configured, as described above, is manufactured in sections measuring 2 feet by 3 feet. The TABI has a density of 9 pounds per cubic foot and has a useful temperature range of 1200° to 1600° F. As compared with other flexible TPS, TABI is easier to configure than Advanced Flexible Reusable Surface Insulation (AFRSI) and is tougher. TABI, when approved for flight, will be installed at two locations on OV-102: the left side forward fuselage and the upper forward fuselage. TABI also has other potential applications, such as the Orbital Transfer Vehicle (OTV).

Possible test locations for Tailorable Advanced Blanket Insulation.
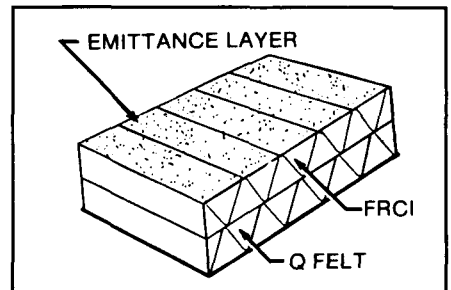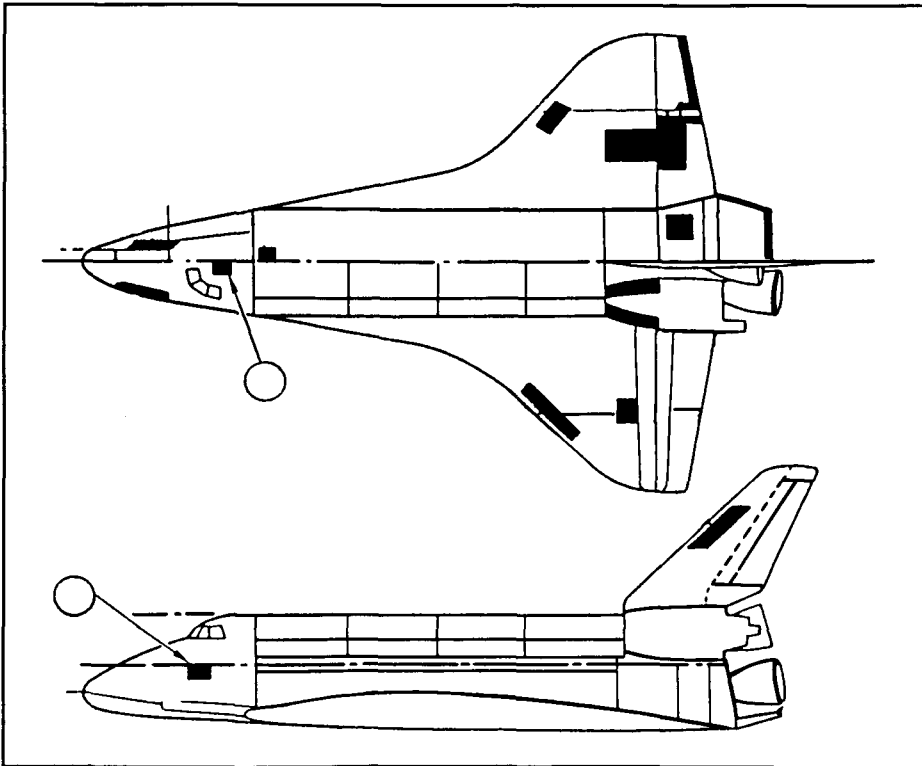
Tailorable Advanced Blanket Insulation.

Integrally-woven core materials.
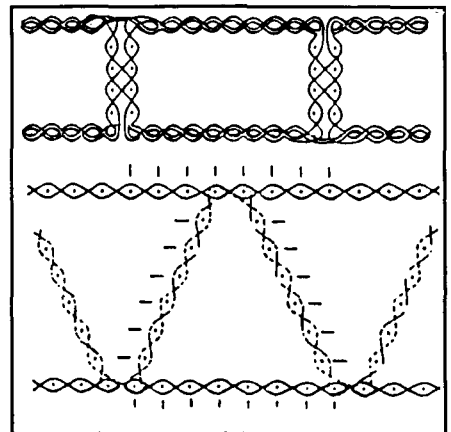
Zero-Gravity Gaging For Cryogenic Fluids

PI: Nancy E. Munoz/EP4
Reference OAST 13

The routine, reliable, and safe handling of large quantities of subcritical cryogenic fluids under conditions of low to zero-gravity is essential to resupply future space-based systems, such as an Orbital Transfer Vehicle (OTV). Cryogenic liquid oxygen (LO$_2$) and liquid hydrogen (LH$_2$) will be handled in large quantities on orbit for use as rocket propellants in a fully reusable space-based orbital transfer vehicle propulsion stage for large payload mass delivery and/or manned missions to geosynchronous orbit. Technology areas critical to on-orbit management of these fluids include storage, thermal control, acquisition, transfer, and quantity gaging. Zero-gravity fluid quantity gaging is an essential element in an integrated quantity gaging system for continuous monitoring of consumables, for determining resupply intervals, and for verification of fluid quantity transferred to or from the user. The Johnson Space Center (JSC) has been tasked to enable zero-gravity quantity gaging system technology, as it has been virtually nonexistent since the early 1970's. This activity will directly support a program undertaken by the NASA Lewis Research Center (LeRC) to enable other critical technology areas for the on-orbit management of subcritical liquid oxygen and hydrogen. The project is titled the Cryogenic On-Orbit Liquid Depot-Storage, Acquisition, Transfer (COLD-SAT), and it consists of a subscale experimental flight test bed to be manifested on the Space Shuttle or on an Expendable Launch Vehicle (ELV).

The objectives of the JSC task are to develop a zero-gravity quantity gaging system capable of an accuracy to within five percent for application to large oxygen and hydrogen tankage to support Orbital Transfer Vehicle refueling and to deliver flight gaging system hardware for test verification in the COLD-SAT. Under this contracted effort, analysis and trade studies were performed to assess candidate zero-gravity gaging concepts. The Radio Frequency (RF) Modal gaging system concept was determined to be the most promising concept which had the capability to achieve within five percent accuracy in zero-gravity. The design of the RF Modal gaging system concept, along with feasibility testing to identify potential problem areas, was accomplished in the previous year's work.

During this fiscal year, laboratory tests were performed to determine the sensitivity of the RF gaging system to more realistic zero-gravity fluid behavior (multiple bubbles, and fluid along the tank walls). Testing last year concentrated on settled fluid cases (single bubble). In fiscal year (FY) 1987, the RF gaging concept was tested in a small-scale tank with multiple antenna positions and several "random fluid" positions. The "random fluid" positions were simulated by creating specially shaped blocks of paraffin wax, which has a dielectric constant close to that of LO$_2$ and LH$_2$. The dielectric constant affects the operation of the RF gaging concept; therefore, the paraffin wax tests should provide a good indication of how the RF gage would operate with LO$_2$ or LH$_2$ in zero-gravity. The tests consisted of sweeping resonance frequencies over a frequency range that was established

through settled ground tests performed in FY 1986. A settled test case was performed with paraffin wax to establish a correlation to last year's test results using LO$_2$, LH$_2$, and liquid nitrogen. Wet wall tests were performed by placing different amounts of the wax along the tank wall to simulate fluid behavior in zero-gravity. Multiple bubble tests were performed next by moving one-fourth to one-eighth mass paraffin globules, which resembled spheres, around in the tank while sweeping over the frequency range. These tests showed some changes in modal frequencies as the globules moved, but the changes were within the boundaries that were expected. Preliminary results of the tests indicate that the RF gaging concept operated as was expected, and there are no show stoppers to date to achieving an accuracy within 5 percent.

ORIGINAL PAGE IS
OF POOR QUALITY

Shaped paraffin wax blocks in zero-gravity gage test tank.
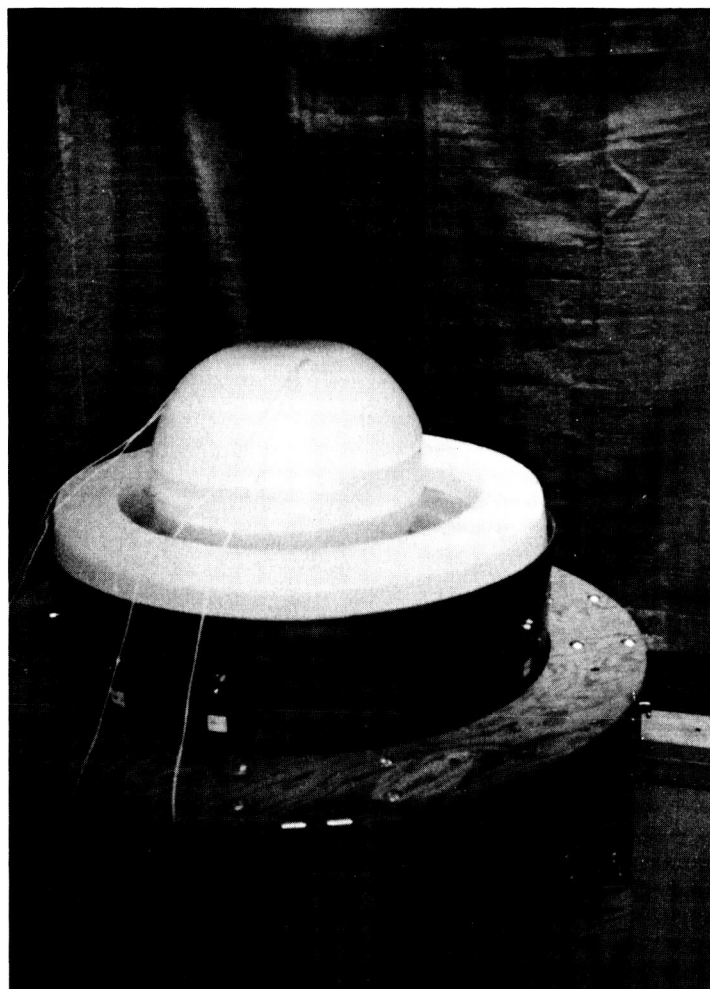
Aerothermal Instrumentation Package

TM: Robert L. Giesecke/EX3
Reference OAST 14

The objective of the Aerothermal Instrumentation Package (AIP) is to provide for the continuing collection of Orbiter entry aerothermodynamic flight data from OV-102 by utilizing existing sensors from the Orbiter's Development Flight Instrumentation (DFI) system. The research and technology application of this data is in comparative analysis of the flight data with wind tunnel and state-of-the-art flow-field computational results. The results of these analyses will provide improved simulation (either analytically or experimentally in ground-based facilities), and subsequent extrapolation to flight for both aerodynamic and thermodynamic environments to which a lifting vehicle is subjected during entry from low Earth orbit.

More specifically, the AIP will provide the primary flight data to support ongoing research activities related to leeside vortex-impingement heat transfer and Reaction Control System (RCS)/vehicle flowfield aerodynamic interactions. In addition, the AIP will provide the necessary "ground truth" correlative data in support of the Shuttle Infrared Leeside Temperature Sensing (SILTS) experiment.

Embedded vortices in Orbiter's leeside flowfield may cause locally excessive heating to the sides of the fuselage. This phenomenon was not modeled in the Orbiter preflight aerothermodynamic database. Flight data analyses have disclosed that the RCS/ aerodynamic flow interactions were not well modeled in the preflight aerodynamic database.

OV-102 was instrumented with temperature and pressure sensors in the upper and lower surface of the wings and in the side surface of the fuselage and fin as part of the DFI system. These sensors were retained when the DFI wiring and hardware were removed from OV-102. As part of the OEX Program effort to use OV-102 for aerodynamic and aerothermal research, approximately 150 of these measurements will be activated by AIP.

The AIP is comprised of a Remote Multiplexer Digitizer Unit (RMDU) and the associated wire harness required to interface the RMDU with Orbiter power, the OEX Recorder, and the existing sensors. The RMDU will be located on an existing shelf in the Orbiter mid-body, below the payload bay liner. The RMDU is a pulse code modulation (PCM) system which will condition and digitize the signals from the sensors and then multiplex them into a single data stream for recording on the OEX Recorder.

The RMDU has been procured and is being flight qualified by Rockwell Space Division. The cable harnesses, the RMDU mounting hardware, the RMDU thermal blanket, and harness attachment hardware have been delivered to KSC.

The AIP has been approved for installation on OV-102 for the STS-32 mission. A partial implementation to support the SILTS experiment for the STS-28 mission has been requested by OEX.

Aerothermal Instrumentation Package.

AIP PCM

AIP TRANSDUCERS

AIP TRANSDUCERS

SSO
- OEX RECORDER
- SYSTEM CONTROL MODULE

- - — MULTIPLEXED DATA
——— SENSOR SIGNALS
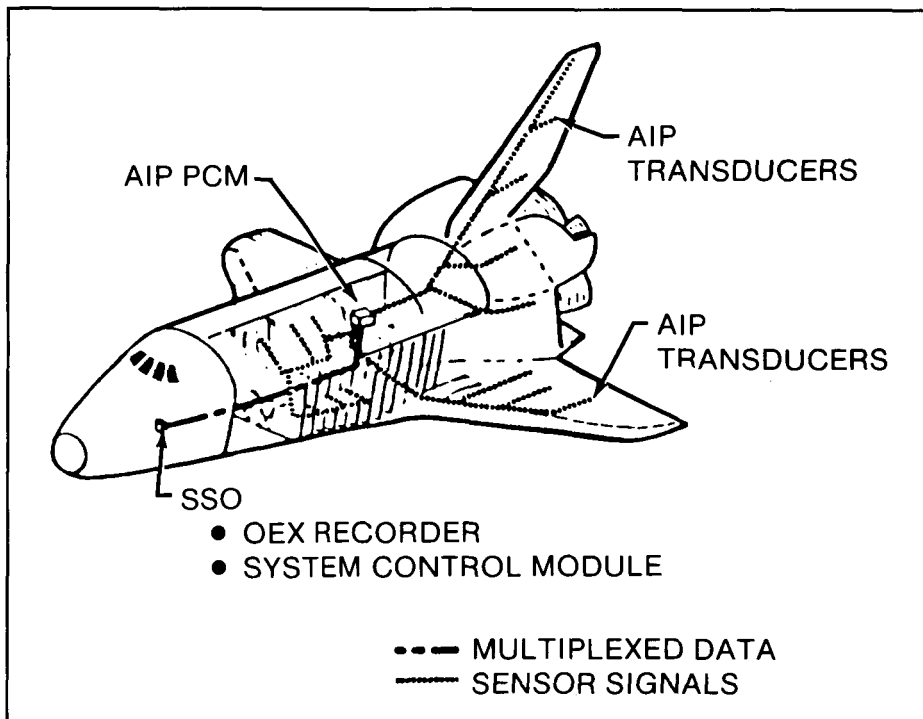
The Orbital Acceleration Research Experiment

TM: M. K. Hendrix/EX3
Reference OAST 15

The Orbital Acceleration Research Experiment (OARE) under development by NASA's Orbiter Experiments (OEX) Program will contain a highly sensitive and accurate electrostatic triaxial accelerometer and data system capable of measuring Shuttle on-orbit linear acceleration into the nano-g range. Its wide dynamic range will permit acceleration measurements during reentry down to an altitude of approximately 60 km. It will, therefore, provide data on rarefied aerodynamics in both the transition and the free-molecular flow flight regimes.

The use of ultrasensitive electrostatic accelerometers in space is not new. Sensor development was initiated as early as 1958, and versions of an electrostatic sensor have been used successfully on several programs. In addition, analyses of Orbiter flight data acquired with the OEX Program's High Resolution Accelerometer Package (HiRAP) have shown that it is possible to use the Orbiter's acceleration measurements to advance aerodynamic prediction technology. However, several problems have arisen in attempting to measure ultra-sensitive accelerations in space. The most significant of these problems have been the bias and scale factor measurements, which are extremely difficult to obtain with accuracy in a one-g environment.

The rarefied-flow regime above an altitude of approximately 90 km is where data for a winged entry vehicle such as the Orbiter are difficult to obtain by wind-tunnel measurements or computational techniques. Therefore, designers who need transitional flow regime aerodynamic data have resorted to empirical formulae based mostly on space-flight data from past programs. This data gap has been partly filled by repeated Orbiter flights with the HiRAP experiment, which have provided some rarefied flow flight data.

Both accelerometer and atmospheric measurements are required to obtain aerodynamic force coefficient information from flight data. Plans include use of atmospheric density data from the Shuttle Upper Atmosphere Mass Spectrometer (SUMS) system especially adapted for the Orbiter by the OEX Program. The SUMS provides data at altitude regions not readily accessible by conventional sounding rockets or orbiting satellites. For OARE initial flights, acceleration ratios will be used to explore energy accommodation coefficients in the free-molecule flow regime as well as angle-of-attack effects.

The OARE results will overlap the HiRAP experiment data previously obtained on OV-099 and OV-102 flights to confirm and extend its results. HiRAP measurements are limited by sensor sensitivity and calibration to about 10 micro-g's. By increasing sensor sensitivity to the nano-g range, OARE will allow measurement of accelerations at orbital altitudes and thus satisfy the need for more precise measurements in this region. The OARE measurements will supply this information in the free-molecular flow regime and will also corroborate the HiRAP measurements in the transition regime. The OARE measurements will also be obtained under varying angle-of-attack conditions to extend the comparisons.

The OARE instrument evaluation development contractor has shown that measurement of nano-g accelerations with long-term accuracy is possible through the use of (1) a highly sensitive sensor with an electrostatically suspended proof mass and high-gain constrainment servo-loops in conjunction with a microprocessor controller, (2) onboard digital filtering for enhanced signal vs. noise discrimination, (3) a 16-bit digital system and sensor auto-ranging which provide a very wide dynamic range, (4) intensive onboard computation with a parallel numeric processor, and (5) onboard calibration of the sensor subsystem to provide a high level of precision and accuracy. A key element for achieving experiment accuracy goals is the use of a highly stable, rotating sensor table which provides a means of performing an inflight calibration of the sensor bias and determining the scale factor. The sensor subsystem and the rotary table assembly are being developed under subcontract to Bell Aerospace and Rexham/Speedring, respectively.

During fiscal year (FY) 1987, the design of the OARE instrument package was completed and a Critical Design Review (CDR) and a Pre-Manufacturing Review (PMR) were conducted. A Software Requirements Review (SRR) and a Software Design Review (SDR) were also conducted. Manufacturing of the OARE hardware was well underway at the end of FY 1987 with integration testing of hardware and software planned to begin in the second quarter of FY 1988.

Orbital Acceleration Research Experiment packaging configuration.
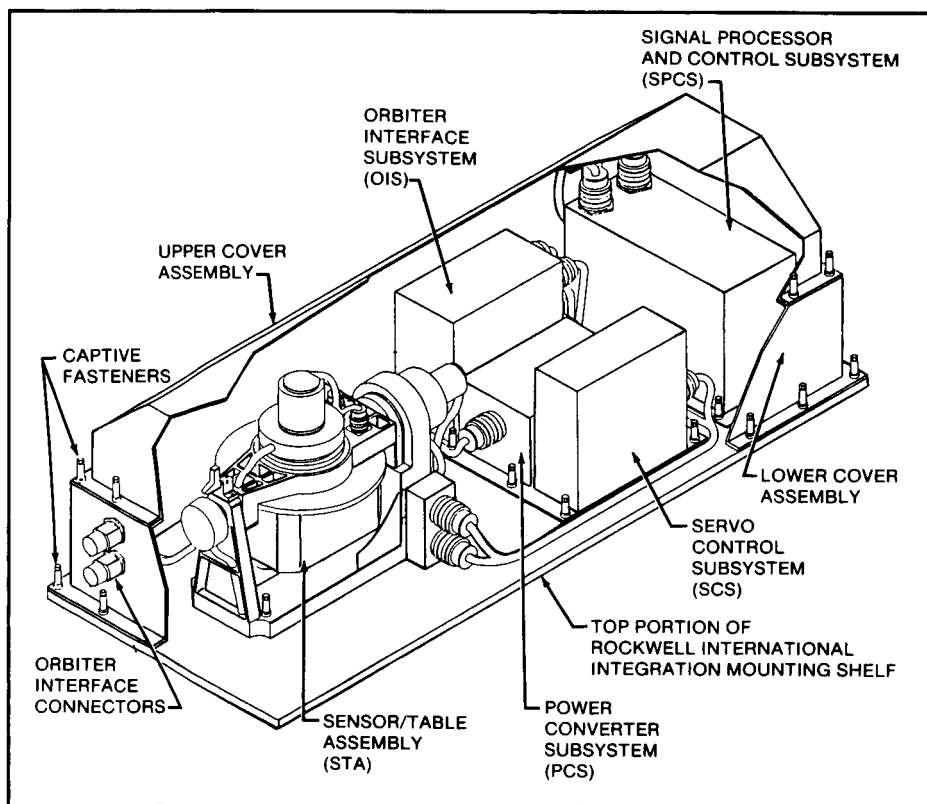
Aeroassist Flight Equipment Aerodynamics/ Aerothermodynamics/ Computational Fluid Dynamics

TM: C. Cerimele/ED3
J. Gamble/ED3
R. Gomez/ED3
M. Jansen/ED3
C. Li/ED3
C. Scott/ED3
Reference OAST 16

Critical to the success of the Aeroassist Flight Experiment (AFE) mission are the preflight predictions of the flow field surrounding the vehicle and the resulting pressure and temperature distributions on the body surface. Predictions of the aerodynamic and aerothermodynamic properties have been obtained through ground testing and computational fluid dynamics efforts resulting in aero/aerothermo data bases, tile designs, onboard experiments definition, and many other design characteristics of the AFE.

Aerodynamics: Midterm preflight definition of the AFE hypersonic aerodynamics based on wind tunnel and computational data has been completed. Consequently, the definition of the center-of-gravity (CG) locus for desired trim angle-of-attack and analysis of longitudinal and lateral stability were performed.

Emphasis was placed on improved definition of the continuum aerodynamics over the preliminary aerodynamic data base. JSC Advanced Program Office engineers monitored the construction and wind tunnel testing of two high fidelity AFE models which include approximate afterbody vehicles. Excellent data was obtained in the Langley Research Center (LaRC) Mach 10 air and Mach 6 CF4 (Freon) wind tunnels. Computational fluid dynamics (CFD) predictions of the wind tunnel results showed good agreement and, therefore, verified the integrity of the CFD codes. Predictions of flight aerodynamics utilizing the inviscid, equilibrium air CFD programs produced the midterm aerodynamic data base. Considerable increase in the pitching moment stability at flight conditions, as compared to wind tunnel conditions, reduced concerns about trim angle-of-attack uncertainty and CG sensitivity. The intended methodology of basing preflight aerodynamics on computational methods (because ground testing facilities cannot accurately simulate the hypersonic, high altitude, real gas flight environment) is a unique and pioneer effort in space vehicle reentry analysis.

In addition, analysis and generation of computer codes and instrumentation for extraction of aerodynamic parameters from AFE actual flight data has been performed as part of the Aerodynamic Performance Experiment (APEX).

Aerothermodynamics: The AFE Aerothermodynamics Methodology Document was prepared and approved. The windward heating distribution on the AFE aerobrake was established on the basis of CFD calculations, as confirmed by wind tunnel measurements. JSC Mission Planning and Analysis Division AFE trajectories were used to generate the time variation of stagnation point heating using the Fay-Riddell theory modified with a suitable factor for nonequilibrium and catalysis effects, including a radiative heating term. The time histories of heat transfer coefficients for about 50 body points on the AFE aerobrake were furnished to the thermal protection system (TPS) designers.

A preliminary design of the Base Flow and Heating Experiment (BFHE) boom has been completed; arcjet test planning is underway. Instrument selection and/or integration is being performed for the heat-flux sensors, pressure transducers, and Langmuir probes. Aeropass operating environments have been predicted on the basis of ground test data and are being folded into the design effort. An overall mission timeline of BFHE instrument operations/sampling rates has been developed, and the BFHE Experiment Requirements Document (ERD) has been written and updated.

Computational Fluid Dynamics (CFD): CFD is being used to predict both the aerodynamics and aerothermal environments the AFE will encounter during its aerobraking maneuvers. CFD results are important since they are able to predict flow conditions which ground based facilities are unable to simulate. Two codes are currently being used in the JSC Advanced Programs Office to perform AFE calculations.

In-house Navier-Stokes/Euler code (NOSIP) has been modified to consider the AFE geometry. Calculations at flight conditions show some disagreement with other published results. To this end, the routines which model the thermodynamic and transport properties of equilibrium air have been replaced with new and improved curve fits. Further calculations using the Navier-Stokes option in the code will be used to determine the heating on the AFE forebody at flight conditions. Another CFD code, the Viscous Reactive Flow code (VRFLO), is being used to predict and understand the real gas effects acting on a complete AFE configuration.

Pressure distribution contours in the pitch plane.
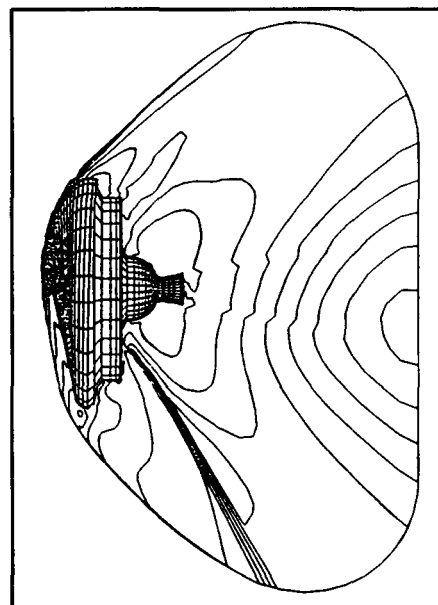
Aeroassist Flight Experiment stagnation point heat flux.
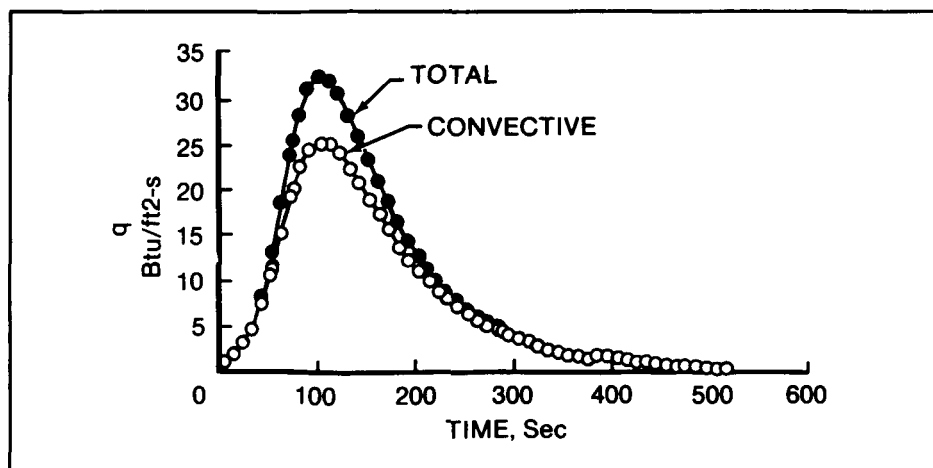
System Control Module

TM: Robert M. Giesecke/EX3
Reference OAST 17

The Space Shuttle Orbiter Experiments (OEX) Project, in support of the Office of Aeronautics and Space Technology (OAST), is responsible for developing specific experiments composed of onboard instrumentation to evaluate the aerodynamic, aerothermodynamic, acoustic, and other stress phenomena involved in spaceflight, particularly during the Orbiter's return to the atmosphere at hypersonic velocity. The project utilizes research-dedicated hardware placed onboard the Orbiter to record specific research-quality data. Data obtained from these experiments is recorded on a flight tape recorder and then transferred to ground recorders upon completion of the mission. During the mission, experiment and recorder control is achieved by commands uplinked from flight control personnel.

In the past, the recorder control had been augmented by the OEX Interface/Control Module (I/CM), which routed the experiment data to the appropriate tracks of the recorder and selected the proper tape speed for the particular data being recorded. Being hardwired and comprised primarily of relays and terminal boards, the I/CM was quite inflexible and had very limited control capability. For example, only two of the recorder's six speeds could be selected, the recorder could only be commanded to advance the tape in the forward direction, and the data could not be switched from track to track during the mission. Because of the latter two limitations, the recorder's operation was constrained to only one pass of the tape, thereby precluding the full use of the recorder's 28 track capability and severely limiting the available recording time.

The addition of more experiments to the OEX project dictated the development of a controller with greater capability. Therefore, the Johnson Space Center developed the OEX System Control Module (SCM). The SCM is a highly flexible, microprocessor-based system that controls the OEX recorder, the experiments, and data system components. The SCM performs its function in response to commands uplinked from the ground or from commands stored within the SCM's memory.

The SCM provides for automatic, semi-automatic, and manual control. In the automatic mode, the experiment operating and recording profile for a particular mission phase can be stored pre-flight in an easily replaceable memory module so that a single command from the ground can activate the SCM for that phase. In fact, the operations relative to an entire mission can be initiated via a single ground command by serially connecting the mission phase profiles stored in the memory. In the semi-automatic mode, new operating profiles can be generated during the mission by uplinking a series of commands to the SCM and storing them in its memory for subsequent initiation by a single command. In the manual mode, the ground controllers exercise individual SCM functions via a series of uplink commands.

The SCM controls the recorder's speed, direction, and track selection and its record and erase functions. It can select any of 32 data inputs and route them to any of the 28 tracks of the recorder and/or to any of 4 line driver outputs to the T-O umbilical. It has the capability of providing 32 power or mode control commands to the experiments or data system components. In addition, it can control the bit rate and format of up to 4 pulse code modulation (PCM) systems.

The SCM provides for snapshot data recording to conserve tape, and automatic track sequencing to extend recording time. In the snapshot mode, relatively short recording periods are periodically alternated with relatively long pause periods when no recording occurs. Automatic track sequencing is an operation in which data is recorded on a group of tracks such that when the end (or beginning) of tape is reached, the data is switched to the next higher group of tracks and recording is continued in the opposite direction.

In summary, the SCM provides a very high degree of flexibility in controlling the OEX experiments and data system components, permits full utilization of the OEX recorder, and reduces the ground controller workload during the missions.

The SCM was designed, fabricated, and flight qualified in-house at JSC. Four units were fabricated: an engineering unit, a qualification unit, a flight unit, and a flight spare. Initial utilization of the SCM will be on mission STS-28, OV-102.
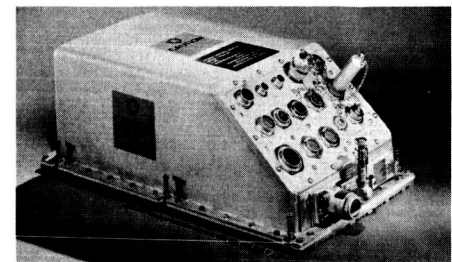
The System Control Module is a versatile, multipurpose system.

System Control Module components.

CONNECTOR PANEL/EMI SHIELD ASSEMBLY

DESICCATOR ASSEMBLY

COVER ASSEMBLY

BATTERY MODULE COVER

CARD CAGE ASSEMBLY

INPUT BUFFER POWER MODULE

OUTPUT BUFFER POWER MODULE

8.7 IN.

POWER SWITCHING ASSEMBLY

BASEPLATE ASSEMBLY

BATTERY MODULE ASSEMBLY

.375 IN.

13.22 IN.

21.72 IN.

TOTAL WEIGHT 56 LBS
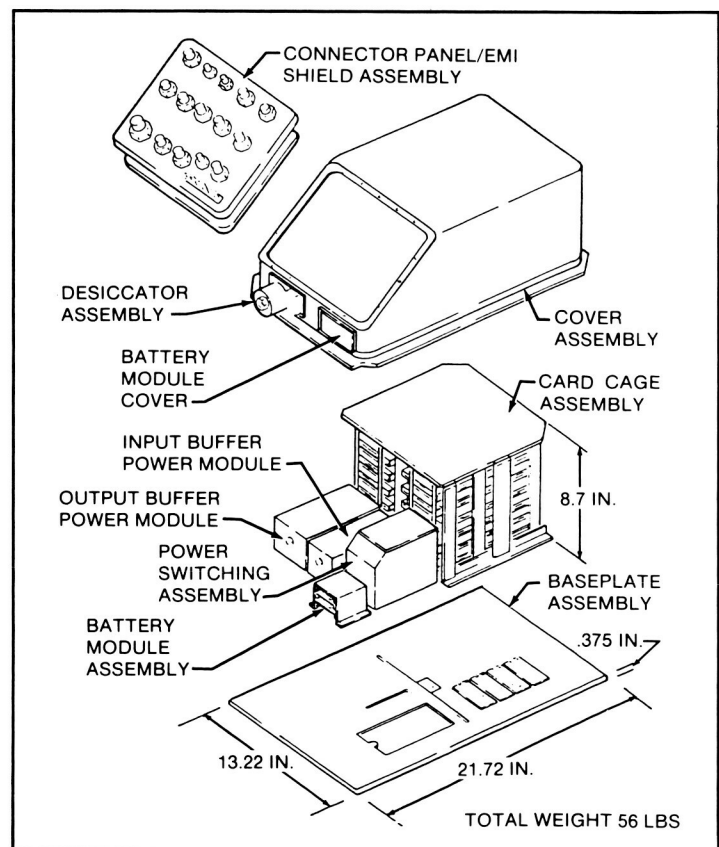
Transportation Technologies Required for New Space Initiatives

PI: Charles J. Mallini/ED23
Reference OAST 18

Four new space initiatives have been examined to determine the transportation technologies which require long lead time development. The results are being documented in a report titled "Transportation Technologies Required for New Space Initiatives." This report considered technologies required for advanced space transportation systems, including both space vehicle and space-based transportation node systems and subsystem technologies. Those technologies that enable or enhance the transportation systems required by the four initiatives are discussed. Earth to orbit launch systems were not considered in this report since they have been the subject of previous technology identification efforts, such as the Space Transportation Architecture Studies and the Advanced Launch System program.

Cassini mission.

The majority of the initiatives were derived from the report "Leadership and America's Future in Space: a Report to the Administrator," S. K. Ride, NASA, August 1987. The four initiatives and their resulting programs were chosen along with related missions to make up the basic scenario from which the various technologies were derived. The initiatives and their programs are defined to the level of detail required to analyze the effects of new technology development. In some cases, this analysis yielded quick, definite answers. In other cases, trade studies are required to quantify the relationship between a technology and a specific initiative and the benefits the technology might provide.

A partial list of the technologies identified in this report includes:

Aero/thermodynamics

- Aerocapture at Earth and Mars
- Computational fluid dynamics
- Advanced thermal protection systems

Systems

- Zero-g transfer of storable propellants
- Zero-g transfer of cryogenic propellants
- Long term zero-g storage of liquid hydrogen
- Energy storage

Guidance, navigation, and control (GN&C)

- Autonomous adaptive GN&C for aerocapture
- Autonomous GN&C for planetary/ lunar
  — launch
  — landing
  — rendezvous
  — docking

Propulsion

- Space maintainable cryogenic engine
- SSME class space startable LO_2/LH_2 engine
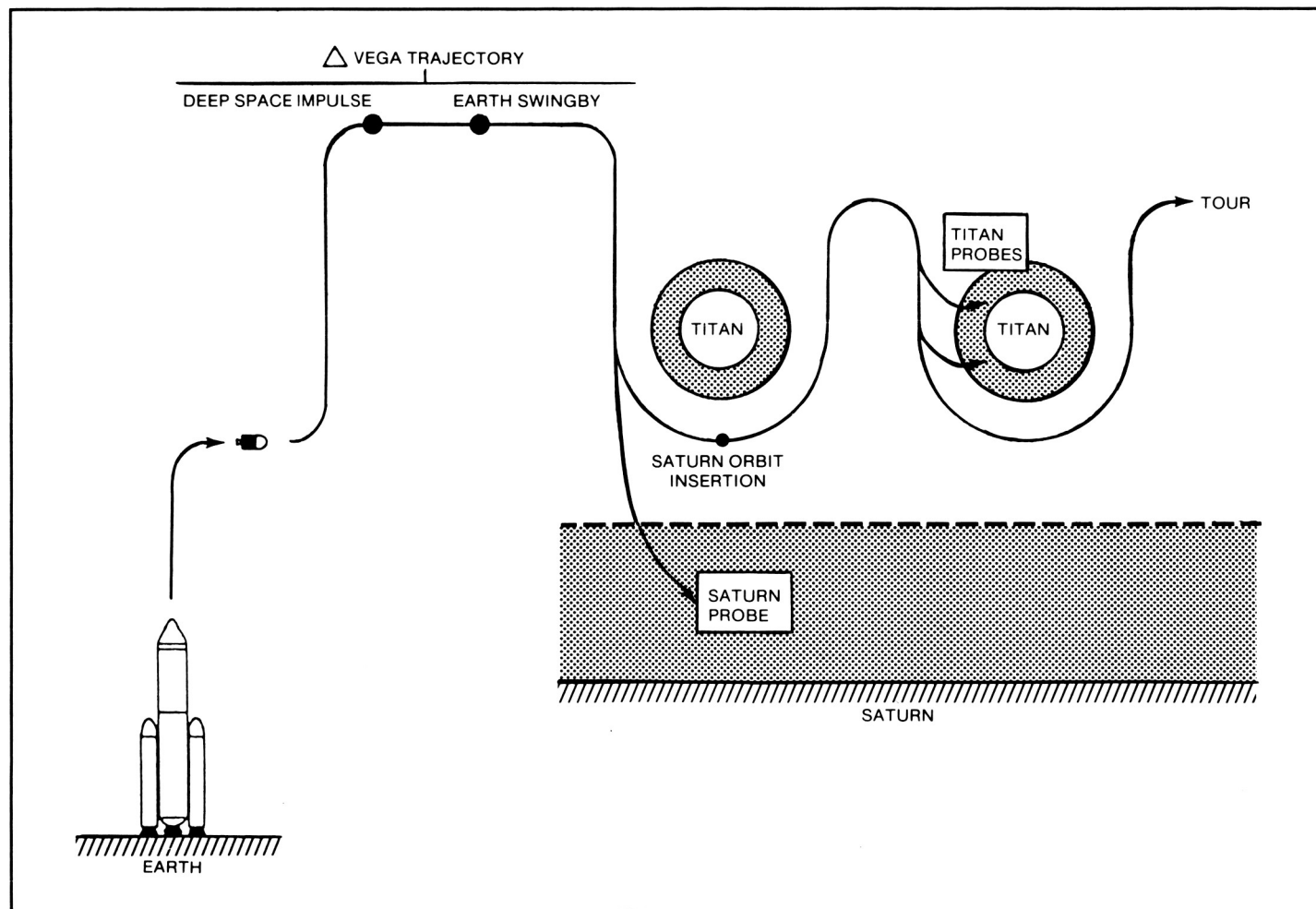
Design Goals and Technology Requirements for Future Launch Systems

TM: Andrew J. Petro/ED2
Reference OAST 19

World leadership in space requires that the United States develop and maintain a system of launch vehicles that assures reliable and efficient access to space. A goal for the Space Shuttle Program was to provide access at a lower cost than expendable launch vehicles, primarily by reusing vehicle hardware. It has become clear in the operation of the Space Shuttle that further reductions in launch costs will require a better understanding of the functions involved in operating launch systems and the relationship between vehicle design features and operational cost. These issues should be considered in the context of an advanced vehicle strategy which may include current expendable vehicles, continued use of the Space Shuttle, evolutionary derivatives of the Shuttle, and a wide range of new vehicle concepts.

A one-year study was begun in June 1987 to define techniques, design features, and new technology which will increase reliability and reduce operating costs for future launch vehicle systems. The study plan includes the following specific tasks:

- Review available documentation on operations of existing launch vehicles, including the Space Shuttle.

- Evaluate the time and manpower expended in all Space Shuttle operations functions, including flight planning, software development and verification, payload integration, training, flight control, and ground operations.

- Survey key Space Shuttle operations personnel for their recommendations on design improvements and applications for new technology.

The product of the study will be a report to include recommendations for the following:

- Technology development efforts which will be most beneficial in improving operations of current and future launch systems.

- Specific test programs and demonstration programs to support technology development.

- Evolutionary improvements to the current Space Shuttle.

- Design features and operations concepts for future launch systems.

The literature review and the survey of Shuttle operations personnel have been completed. Evaluation of this information and additional study will lead to recommendations in the final report.

Some preliminary observations can be made on the basis of the information collected. The complexity and associated cost of operating the Space Shuttle system are more a consequence of the operational philosophy than any design features or technological limitations. Therefore, applications of advanced technology in future vehicles are unlikely to result in a reduction in operational cost unless there is a substantial change in the operational philosophy. For example, the requirements for operational flight planning tools and the flight test data needed to implement these tools must be identified as part of the program plan. In general, the preliminary results of this study indicate that there is great potential for improving the efficiency of the current system and evolving the Shuttle into a truly operational space transportation system.

Space transportation evolution.
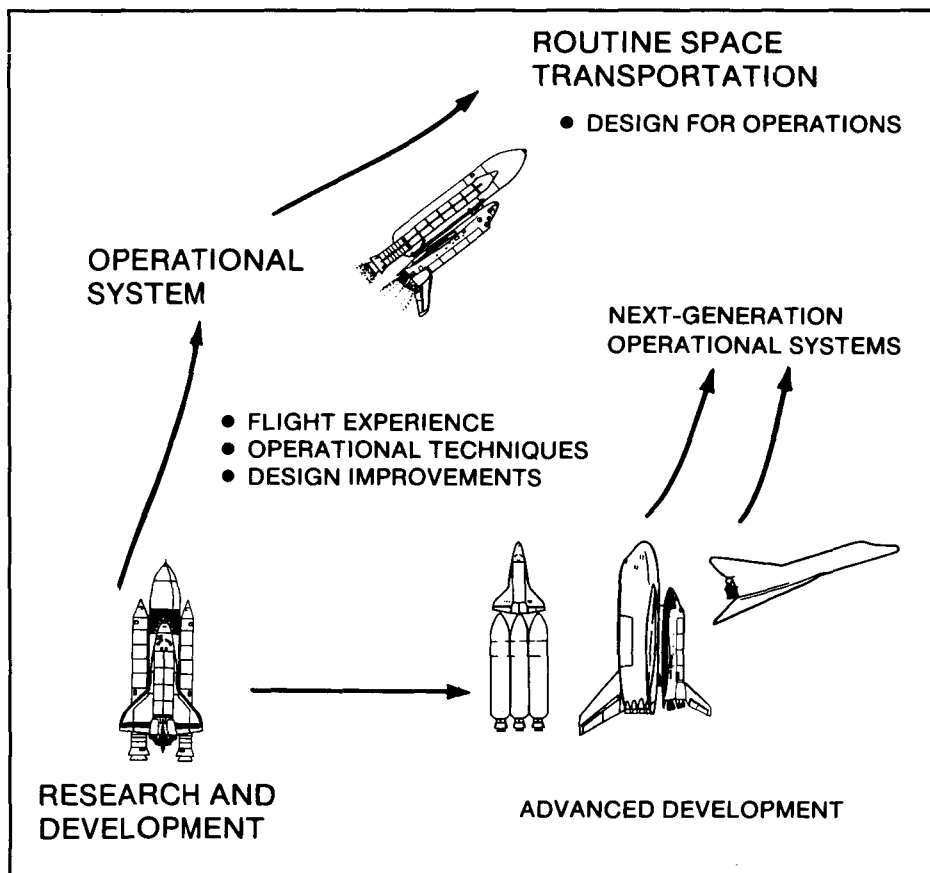
Space Flight
Advanced Programs

Summary

71

Office of Space Flight

Summary

The Office of Space Flight (OSF) Advanced Program activities are primarily directed toward enhancing and expanding the National Space Transportation System (NSTS), focusing on other means of space transportation, and providing a platform for some long range planning in proposed space exploration.

During this past year, the majority of the Johnson Space Center's work has been directed to STS activities and the safe return to flight. However, a steadily growing number of activities have been directed toward improving man's capability and access to the space environment (i.e., development of space suits, data and verbal communications, on-orbit operations and orbital transfer vehicles). Likewise, in support of long range goals and objectives, efforts have been focused on manned and unmanned vehicles and their associated requirements for planetary exploration activities (i.e., proposed unmanned Mars sample return mission and manned lunar and Mars initiative).

Manned Orbital Systems

In support of the overall manned orbital systems, the Johnson Space Center continues to analyze the environmental needs of future manned space missions. Many advanced missions such as geosynchronous orbit (GEO) sorties, lunar base operations and manned missions to Mars have been identified which have diverse Environmental Control and Life Support System (ECLSS) requirements and design drivers. In addition there may also be other types of missions different from the current NASA-directed manned space missions. Despite the uncertainty about specific missions in the future, there is little doubt they will have larger crew sizes and longer resupply periods, if any. These two factors favor the use of a more expendable-free closed loop approach to ECLSS technology. A comprehensive study program was completed which has provided a proposed technology
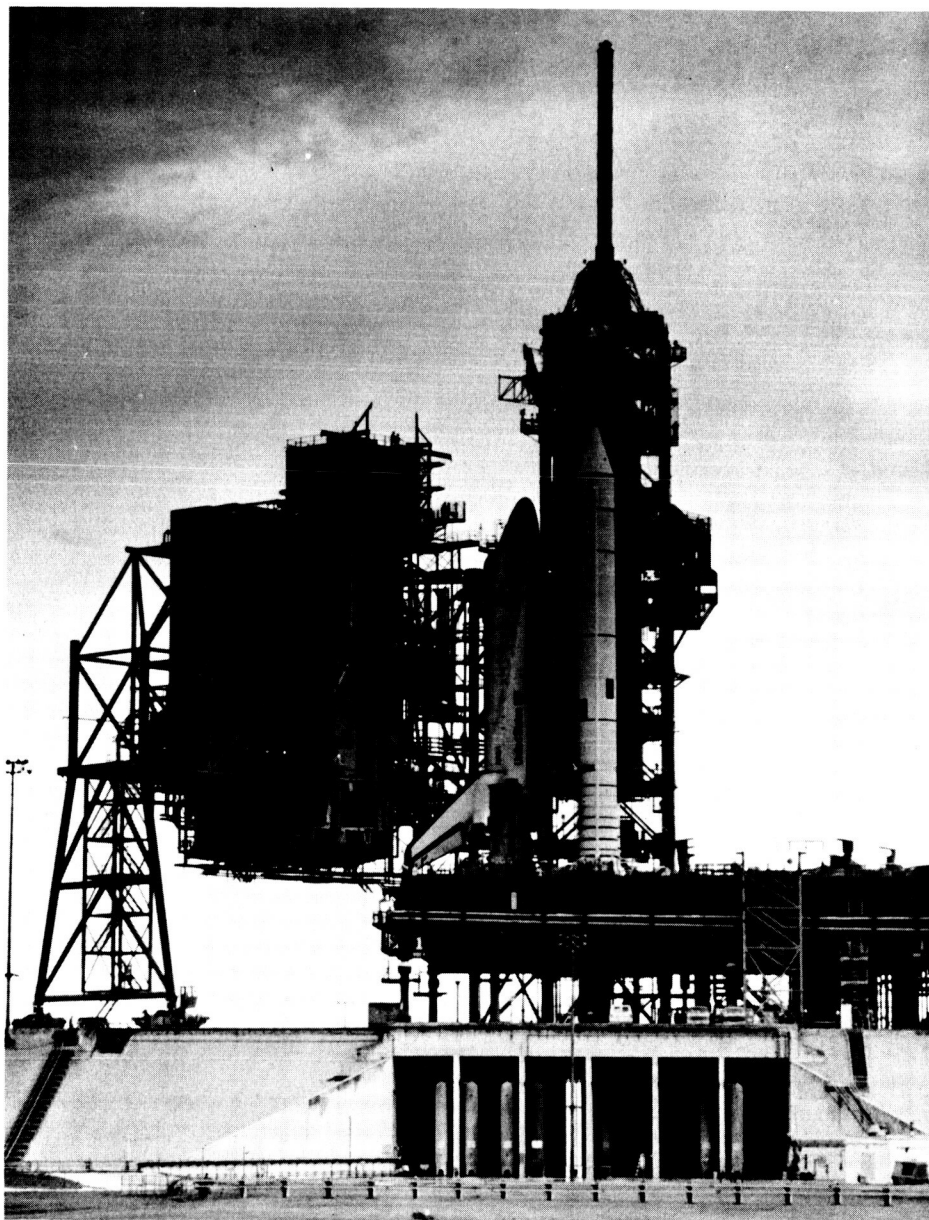
The Space Shuttle Orbiter _Columbia_ at Launch Pad 39A.

research and development plan with schedules, cost, and priorities for the next 50 years.

Increased extravehicular activity (EVA) requirements of the current Space Shuttle missions and the developing Space Station Program have emphasized the need to define future EVA mission operational requirements, to establish the resulting EVA hardware requirements, and to assemble a schedule to ensure timely EVA technology development. In order to establish
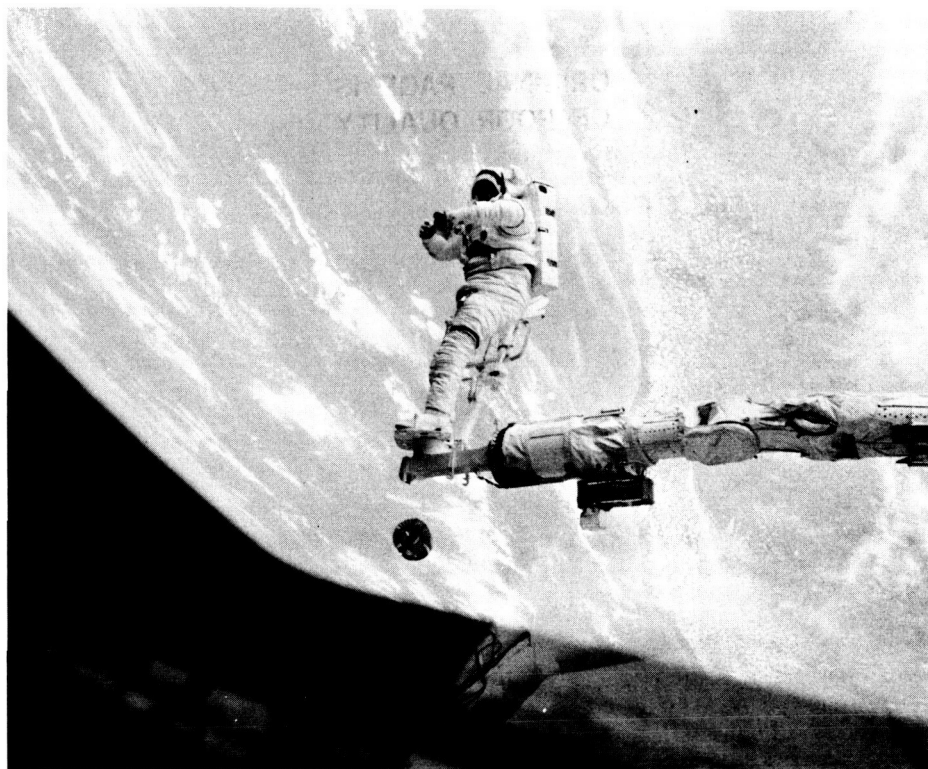
Astronaut engaged in extravehicular activity.

these baseline EVA requirements now, JSC has, in conjunction with in-house efforts, implemented several major study contract efforts. The results of these efforts will be available in FY 1988.

Work continues this year on improvements to the EVA glove design and overall performance. Advancements have been made in the development of two independent "soft" metacarpal joints designs through the use of improved gathered restraint fabric pattering and link-net cord construction. Efforts will continue to design upgrades to the mobility features as well as to the thermal micrometeoroid protection coverglove materials layup, patterning and attachment techniques.

Advanced Transportation

In an effort to be prepared for future launch missions, JSC has begun to establish informational data bases which will provide identification of enabling/enhancing technologies required and to develop analysis tools to support the analysis of future launch missions. One such venture has been the task of designing and evaluating a partially reusable advanced launch system which consists of a reusable booster and an expendable second stage with emphasis on the trade-off analysis between glideback and flyback boosters.

JSC has continued the analytical efforts of using the Space Shuttle-derived high altitude density information to develop a statistical data base which will improve the analytical atmospheric models for the mesosphere region. On the basis of the limited data, it is unlikely that a comprehensive analysis can as yet be performed with these data to uniquely determine latitudinal or seasonal variations which can be utilized for model improvements. However, the HiRAP data, in conjunction with the existing IMU-derived atmospheric data, can be utilized by trajectory analysts for future spacecraft design studies.

Satellite Services

Studies of the populations and hazards of man-made orbital debris continue at JSC. As of January, 1988, indications are that there are some 7,030 man-made objects currently in space. This represents about a 10 percent increase over the past year. The major source of these objects continues to be satellite breakups and/or explosions in Earth orbit. Currently the U.S. Space Command, using ground-based radars, maintains a catalogue of the larger orbiting objects. During the past year, a conceptual design for an improved ground-based radar

system has been developed that is optimized for the detection of smaller orbital debris.

Work continues on defining the requirements and providing conceptual designs of various items of satellite services equipment. The major contributions this year have been the design of a versatile, lightweight satellite-holding device; the formation of a JSC Satellite Service System Working Group; the development and demonstration of a force/torque sensing electromagnetic device; and the formulation of a joint NASA/DOD study program called "Satellite Assembly, Maintenance and Servicing".

Engineering efforts continue to pursue the development of high-speed graphic efforts to facilitate the analysis of complex control problems. Two particular advantageous applications are multibody proximity operation problems and control systems analysis involving sophisticated dynamics, such as large flexible space structures. Analysis assessments, which are cumbersome using two-dimensional plots may be readily concluded by the use of three-dimensional dynamic representations. Toward this end, a basic designer laboratory has been established which allows the control designer to rapidly assess the effect of his design iteration on a complex control problem.

Future efforts will be centered around control system analysis involving sophisticated dynamics.

It has been recognized for some time that there are many space-related operations which can be improved with the advent of some form of robotic vision tracking sensor. Many of these operations, which presently rely on an astronaut for manual control and manipulation, can be enhanced in the areas of efficiency, accuracy, repeatability, and safety. For this purpose, JSC has been involved with the development, testing, and evaluation of a tracking sensor device as an aid for proximity operations and "eye-hand" coordination of robotic manipulators during satellite servicing.

Advanced Concepts

A number of related tasks are being pursued in the technologies andcapabilities of expert systems, which are computerized programs that emulate complex human expertise in a well-defined problem domain.

The advent of long-duration, manned spaceflight programs, requires attention be paid to designing systems that can be replaced, maintained, shared, and upgraded

with minimum impact. Reusability and maintainability of software and hardware systems for long-life-cycle systems have resulted in the need for "commonalty" of system resources. JSC's effort in 1987 focused on developing preliminary commonalty concepts and providing a catalyst for the establishment of management and organizational elements to promote commonalty in flight computing systems.

Another area of interest has been the development of a production-quality system that could be described as an "application generator generator" that is a knowledge-based environment for the construction of special-purpose systems for the generation of applications software by the end-user with the domain of interest. During 1987, the problem-solving architecture and the

basic knowledge acquisition algorithms were designed and implemented, and the target language reusable components library was selected and installed. Work has begun on initializing the cataloging of the system. Likewise, for the total utilization of the capabilities of a graphics package, a prototype generator has also been developed to enhance the user's analysis capabilities for a variety of simulated scenarios.

JSC also has continued the analysis of a proposed rendezvous expert system that would operate in a real-time environment and could interface with the flight crew and/or flight subsystems. Rendezvous operations were chosen as the focus for a development effort. A prototype rendezvous expert system was developed and demon-

strated. Current efforts are focused on the implementation of this developed system on a major real-time engineering simulation facility, the JSC Systems Engineering Simulation (SES) Laboratory.

Currently, most computational applications require integration of an expert system with conventional software on conventional computers. This has proven to be difficult with existing expert systems tools. JSC's current goal is to redevelop the integration tool in Ada so that it will be compatible with the cost effective Ada environment.

In the field of optical communications systems, a study is continuing to determine the best total system design to use for a given short range, non-line-of-sight infrared communication application. Applications that are currently under consideration are multi-user, multi-access voice/data communication; biomedical data links; robotic control; and magnetic end effector data transfer.

To prepare for meeting the challenges of future advanced missions, introduction of new research and development programs must be initiated in order to later make the mission technologically and economically feasible. This requires the identification and acquisition of scientific and engineering data concerning the advanced missions requirements. Economics, as well as the timing, play a major role in the eventual definition of these development programs.

Two mission specialists repairing the "captured" Solar Maximum Mission Satellite in the aft end of Challenger's cargo bay.

Advanced Planning

JSC has been active in developing a variety of tools to support conceptual design and strategic planning studies. A major element of this sort of preparation has been the development of a cost estimating model for future space program initiatives. Work is being done on cost modeling, data base enhancement, a designers catalog, cross cultural studies, and software development. The overall objective is to develop a model which will be adaptable to many different kinds of space hardware and will be able to take into account changing technologies and evolving programmatic trends.

Currently, national efforts are underway to develop a mixture of new space launch systems which will meet the demands for placing payloads into Earth orbit in the 1990's and beyond. These future launch vehicles have a requirement for an order of magnitude reduction in total life-cycle cost compared to today's systems. In support of this endeavor, JSC has begun development of a informational data base which will

Lunar base concept.

enable the eventual development of an autonomous ascent guidance system; namely, systems that show promise of reducing the life-cycle cost of such a system while supporting enhanced crew safety and vehicle reliability.

In preparation for future missions and exploration programs, JSC is in the midst of assessing the current and future external and internal environment, strategy formulation to map current status into future projects, and development of an implementation plan. Currently, JSC is reviewing the future requirements, with emphasis on under-standing the technologies, or more generally the capabilities, that will be required within the next decade. A major portion of this activity will encompass space transportation systems, with regard to lunar bases, capability of delivering the base hardware, and resupplying the inhabitants.

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Space Flight
Advanced Programs

Significant Tasks

Environmental Control and Life Support Technology Study for Advanced Manned Missions

PI: Chin H. Lin/EC2
      Melaine M. Sedej/EC2
Reference OSF 1

As the design phase of the Space Station is underway, the Johnson Space Center (NASA JSC) is beginning to analyze the needs of future manned space missions. Many advanced missions such as a lunar base and a manned mission to Mars have been identified which have diverse Environmental Control and Life Support System (ECLSS) requirements and design drivers. Many requirements are different from those for prior NASA-directed manned space missions. Despite the uncertainty about specific missions in the future, there is little doubt they will have larger crew sizes and longer resupply periods, if any. These two factors, larger crew sizes and longer resupply periods, favor the use of a more expendable-free closed-loop approach to ECLSS technology. Virtually all of these future missions will require ECLSS technology that further eliminates the expendables and launch weight penalties associated with the currently baselined partially closed-loop Space Station ECLSS.
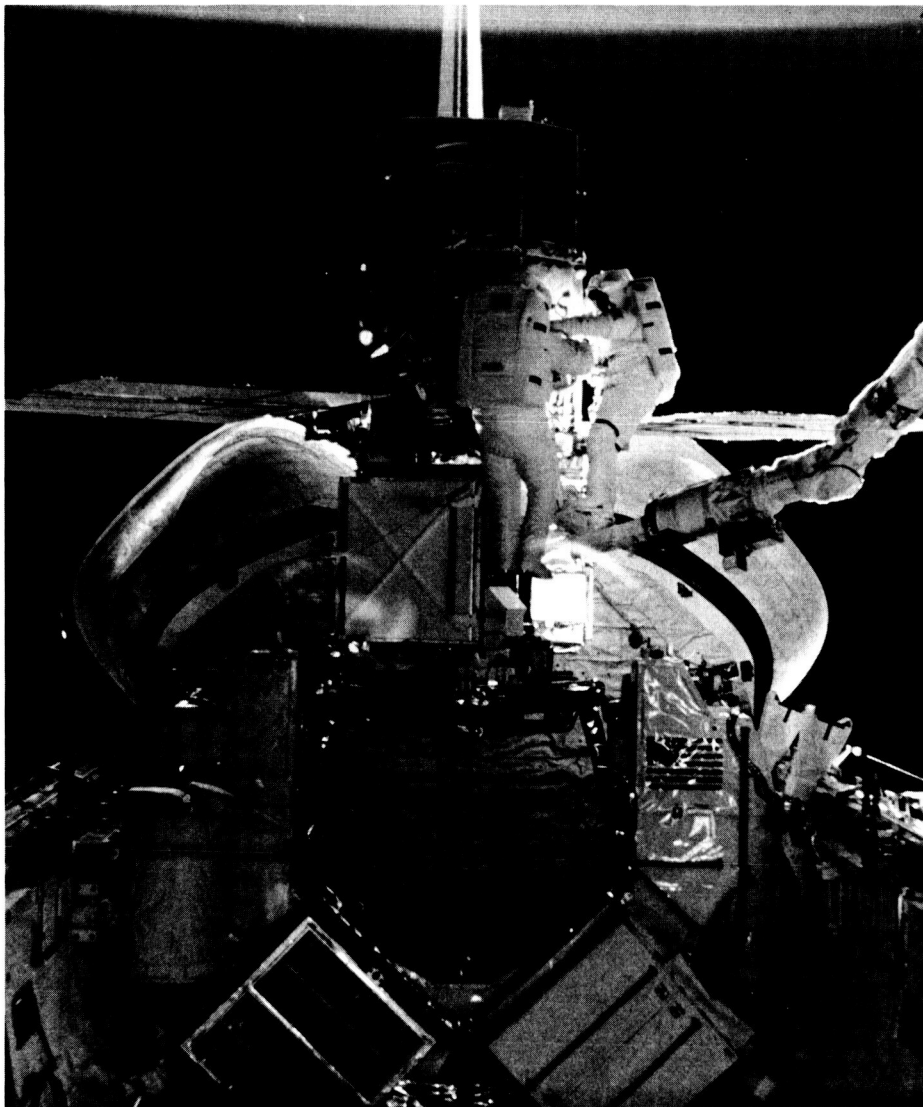
To prepare for meeting the challenges of these future advanced missions, introduction of new research and development programs must be initiated now in order to make the missions technologically and economically feasible later. This requires the identification and acquisition of scientific and engineering data concerning the advanced missions and their ECLSS needs. Then ECLSS's must be conceptualized which would be safe, reliable, and maintainable. Timing and funding play a major role in the definition of the associated ECLSS development programs. Furthermore, a plan must be conceived to schedule and fund the ECLSS programs. Such efforts are needed to evolve the technology and achieve revolutionary advancement in the same manner as for the Space Station ECLSS. That is, many ECLSS programs were initiated 5 to 25 years ago so that the technology would be available today to produce the ECLSS hardware for the initial Space Station within the allowable life cycle costs.

A 19-month study program to conduct a comprehensive survey of the existing and potential regenerative ECLSS technology, including both physiochemical and biological concepts, was completed in July 1987. The study includes an evaluation of potential synergism between the ECLSS of the Space Station and future advanced missions and identifies voids and needs of ECLSS technology development. Completed program tasks include definition of ECLSS requirements for advanced space missions, identification of unique mission drivers, development of a trade methodology and assessment of existing ECLSS technology capabilities, and identification of new ECLSS technology needs. As a result of the study, a technology research and development plan with schedules, which are shown in the figure; costs, which are identified in the table; and priorities has been established to fit long, medium, and short term NASA advanced mission requirements for the next 50 years.

PROJECTED COST FOR THE NEEDED ECLSS TECHNOLOGY PROGRAM

Project Number		Total Cost, dollars
1	Water Management System Technology	22,850,000
2	Atmosphere Management System Technology	21,070,000
3	Waste Management System Technology	12,260,000
4	Food Management System Technology	90,650,000
5	Component Regeneration System Technology	9,620,000
6	Growth Space Station Technology	16,250,000
7	Lunar Base Enabling Technology	16,450,000
8	Mars Transfer Vehicles/Base Enabling Technology	27,000,000
9	Long-Life Operating Data Base Generation Technology	25,800,000
10	Opportunity Creating Research Technology	8,050,000
		250,000,000

Assumptions: Calendar year 1986 dollars

Advanced ECLSS Needed Technology Project schedule.

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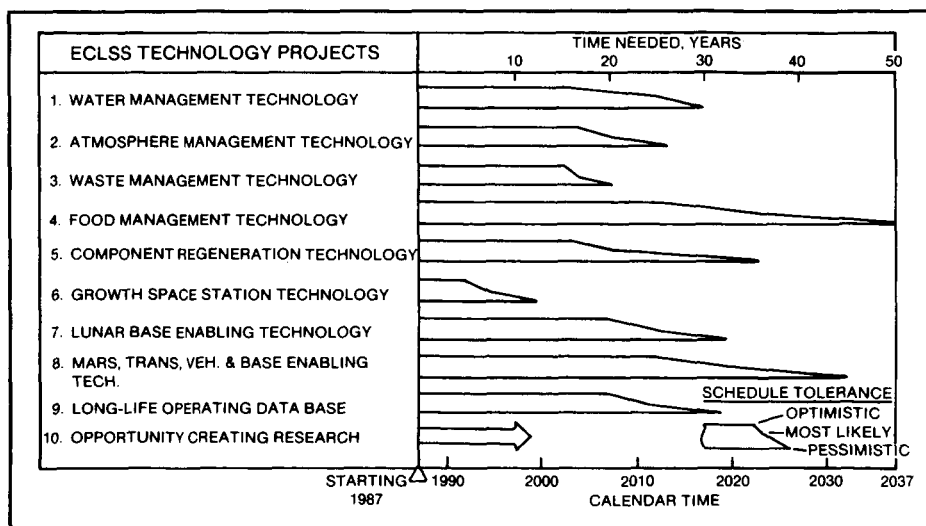
Advanced Extravehicular Activity Systems Requirements Definition Studies

TM: Terry O. Tri/EC3
Reference OSF 2

As outlined by JSC's Strategic Game Plan, advanced manned missions beyond low Earth orbit are projected to play a significant role in America's future space program. One of the many diverse aspects of past and present manned space missions which has proven to be key to overall mission success has been extravehicular activity (EVA), and it is projected that EVA will continue to be an integral part of future manned space missions. By establishing baseline EVA mission requirements for such future activities now, NASA can implement the evolutionary technology development activities required to provide advanced EVA hardware for these future missions when they become realities.

In order to establish these baseline EVA requirements, JSC has initiated parallel efforts with Essex Corporation and Arthur D. Little, Inc. The specific program objectives are to define future EVA mission operational requirements, to establish the resulting EVA hardware requirements, and to assemble a technology development schedule to ensure timely EVA technology development. Through a three-phase study effort, Essex will focus on three distinct future manned mission scenarios: geosynchronous orbit (GEO) sorties, lunar base operations, and Mars surface exploration. A. D. Little will address the latter two scenarios through a comparable two-phase study effort. Each phase of study for both contractors will span eight months.

Just nearing completion of its first study phase, Essex has developed a baseline manned GEO mission scenario in which a failed teleoperated retrieval device is to be disengaged from a failed geosynchronous satellite, and the satellite is to be repaired by means of manned EVA. In compiling and assessing the various impacts to EVA requirements posed by this mission, Essex has addressed three key groupings of requirements:

- Environmental parameters to which the EVA crew is subjected and the resulting biomedical impacts to them from such aspects as temperature extremes, high radiation doses, fatigue, etc.

- Task and mission requirements in which the capabilities and limitations of suited crewmembers are considered with regard to the specific activities they would likely be performing during EVA.

- Hardware requirements which are developed through assessing the required EVA man/machine interfaces and then determining the necessary capabilities of the advanced EVA hardware.

Upon compiling these widely ranging requirements, Essex has assembled an advanced EVA technology development schedule that outlines the various technology areas which are key to the development of advanced EVA hardware and which require bolstering to ensure timely development.

Just beginning its first work phase, A. D. Little has developed an initial lunar base construction EVA scenario and has begun to compile the various environmental, physiological, and technological data necessary to complete a comprehensive technology requirements definition for lunar EVA.

Both advanced EVA study efforts are scheduled to run through 1988 and will be completed in 1989.

Task flow diagram for each study phase.
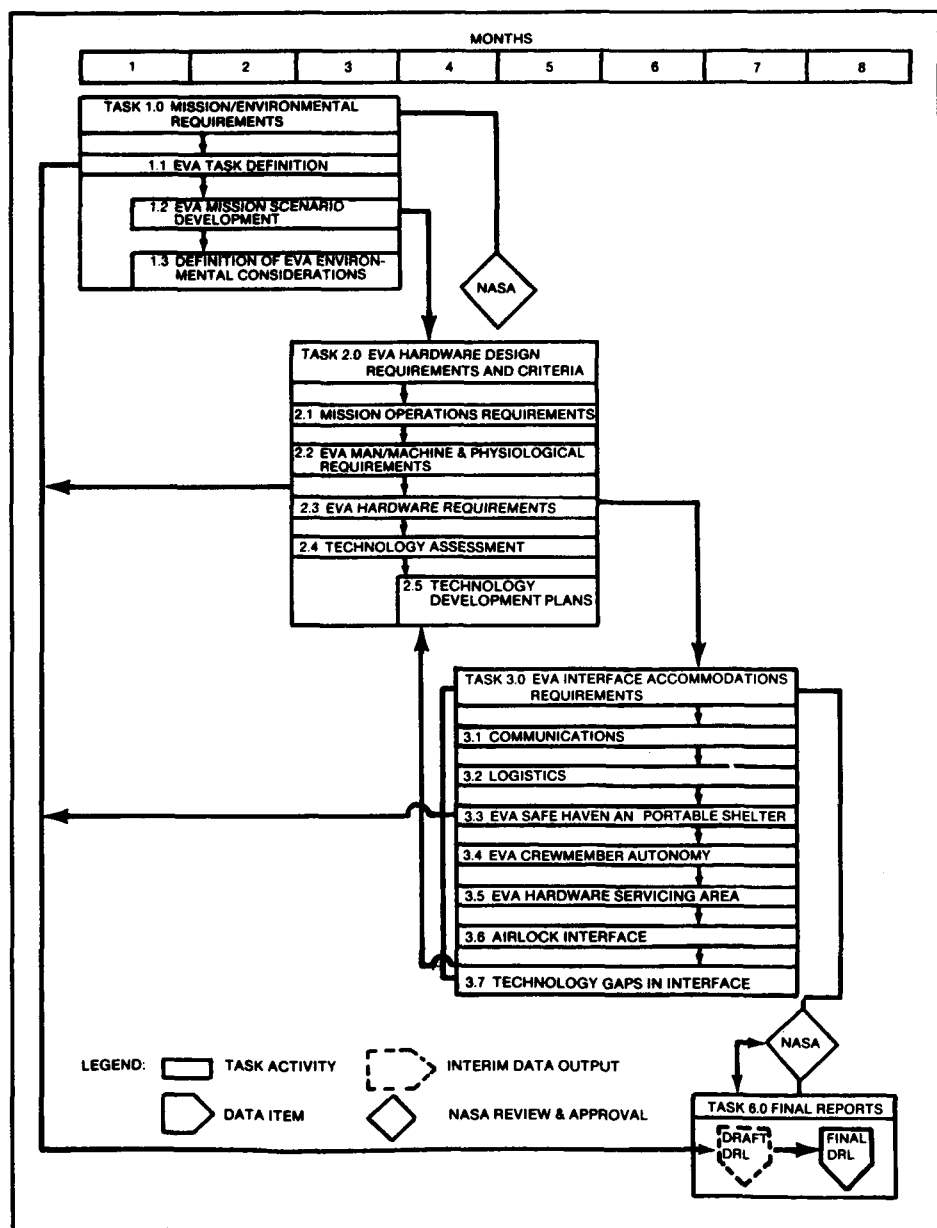
Advanced Extravehicular Activity Glove Development

TM: **Joseph J. Kosmo/EC3**
Reference OSF 3

Space suit glove assembly development, starting with the Mercury Program, has progressed to its present status as a result of the changing goals and design philosophies of each unique manned space mission. The early period of space suit glove development relied heavily on military high-altitude, full-pressure suit technology. This was typical of the Mercury and early Gemini Programs. Longer spaceflights and the advent of extravehicular (EV) operations required drastic improvements in the areas of comfort, mobility, and the incorporation of an EV hazards protective coverlayer. Early EV gloves remained clumsy, fatiguing, and uncomfortable and were the single most limiting factor in manned extravehicular activity (EVA) performance.

The current advanced glove designs represent a series of evolutionary engineering efforts aimed at systematically improving higher operating pressure EV glove performance capabilities. The key glove performance issue becomes one of finding the proper balance between the basic protective requirements (i.e., EV environmental hazards) and the performance requirements of the fundamental glove assembly. Gloved hand productivity for EVA requires a high degree of mobility, comfort, and tactility as well as safety assurance. Glove design complexity increases with the differential pressure between the glove and the vacuum of space and with the EVA mobility task requirements.

In order to maintain and improve EVA glove mobility features for higher operating pressure (8.3 psi) glove assemblies, a series of mobility joint elements are currently under development. Low-torque finger joint elements consisting of tucked fabric material as well as a woven, link-net cord construction are being investigated. Probably the most critical joint area of the glove, considering overall functional performance application for grasping and finger/thumb opposition tasks, is the metacarpal joint. Metacarpal joint designs are being pursued that incorporate low-torque, rolling convolute design features. A rolling convolute joint design is also being pursued for the glove wrist joint.

The rolling convolute metacarpal joint incorporates a system of hard ring elements linked together on opposite sides of the hand through a pair of pivot bearings. The joint system exhibits extremely low torque

forces and helps reduce overall hand fatigue during grasping operations. Efforts are underway to reduce the rolling convolute ring hardware profile and bulk in order to further enhance grasping capability. Advancements have also been made in the development of two independent "soft" metacarpal joint designs through the use of improved gathered restraint fabric patterning and link-net cord construction. Parallel glove development and fabrication activities have been pursued under NASA JSC contract by both David Clark Co. and ILC/Dover, Inc.

Prototype models of the 8.3 psi glove assemblies being developed by the contractors were delivered to NASA JSC for preliminary test and evaluation activities. A series of glove box tests were conducted with astronaut crewmembers to evaluate overall mobility joint design concept features, comfort, and fit of the various configurations. An initial Weightless Environmental Training Facility (WETF) test was successfully completed with a representative 8.3 psi glove assembly prototype.

Efforts are continuing for design upgrades to the mobility features of the current glove prototypes, based on the positive results of the recent manned testing activities. In addition, design and fabrication improvements are being made to the thermal micrometeoroid protective coverglove materials layup, patterning, and attachment techniques to minimize its corresponding integration impact on the basic pressure restraint glove mobility features.

Extravehicular activity glove development.
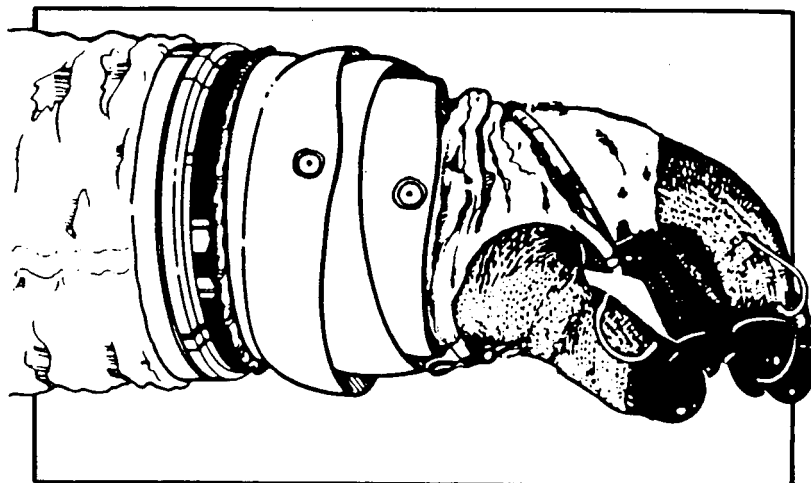
KEY FEATURES
- **LINK-NET AND TUCKED-FABRIC FINGERS**
- **METACARPAL JOINT**
- **ROLLING-CONVOLUTE WRIST JOINT**
- **MODULAR CONSTRUCTION FEATURES**
- **FINGER LENGTH ADJUSTMENT**
- **LOW-TORQUE WRIST BEARING**

Launch Vehicle Synthesis and Program Enhancements

PI: Charles J. Mallini/ED23
Reference OSF 4

Space activities over the next 25 years will require cost-effective, reliable, and robust access to space. Current systems lack the low cost, capacity, and operational flexibility to meet those future requirements. Evaluation of future launch systems, identification of enabling/enhancing technologies required, and the development of analysis tools to support this effort are the primary objectives of this task.

The activity within this has been concentrated on the design and evaluation of a partially reusable advanced launch system which consists of a reusable booster and an expendable second stage. Preliminary payload capacity of the system is 150,000 pounds. Several studies are in progress which are focusing on launch system staging configuration, propulsion system, propellants, engine-out sizing methodology, and staging velocity. All the configurations under study use a flyback booster as a method to reduce expended hardware cost. Analysis is underway to study the impacts of a glideback booster versus a flyback booster which uses airbreathing flyback propulsion systems.

Initially the staging Mach number has been limited to Mach 3. This was found to be the highest staging Mach number which will allow a booster to glide back to the launch site. Further studies will focus on higher staging velocities which will reduce the size of the second stage. The higher staging velocities will require a flyback propulsion system for the booster.

Identification of long lead time technologies which will enable or enhance the overall system is an integral part of the overall task. One example is the use of propellant crossfeeding in parallel staged configurations. It has been shown that propellant crossfeeding will reduce overall launch mass by approximately 1 million pounds. Several areas of concern exist for propellant crossfeeding, including propellant dynamics, cavitation at staging, and reliability. Propellant crossfeeding has been identified as a new technology development candidate which will enhance parallel staged configurations.

To support the complex trajectory designs which are required to accommodate the glideback and flyback boosters, several enhancements have been required for the in-house trajectory analysis program, Simulation and Optimization of Rocket Trajectories (SORT). This effort has produced a state-of-the-art trajectory simulation using Fortran 77 code, strict coding standards, highly modular code, and an input processor which aids the user during the development of the input stream. The SORT program is used in industrial facilities, such as General Dynamics, Lockheed, McDonnell Douglas, and Rockwell and in Government facilities around the country, such as the Johnson Space Center, Marshall Space Flight Center, and Lawrence Livermore Labs.

Future work will begin to address the relationship between design characteristics and the cost to implement and operate them over the long term. Evolutionary considerations will also be taken into account, relative to current systems.

Partially reusable launch vehicle.
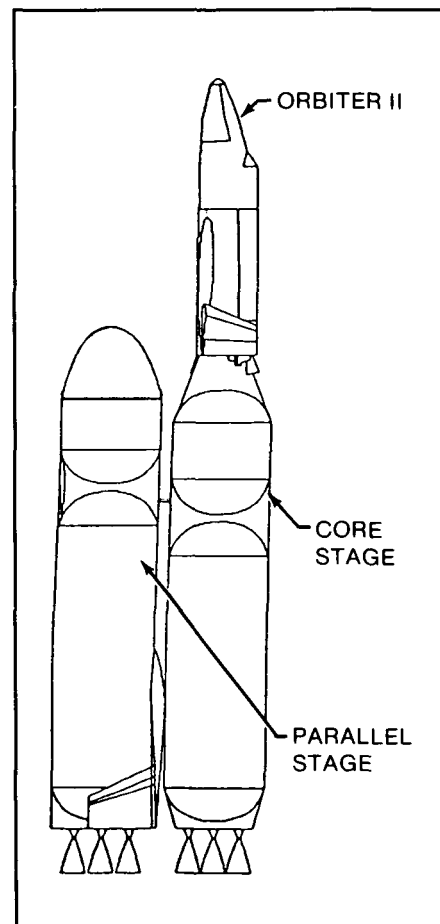
Space-Shuttle-Derived High-Altitude Atmospheric Density Model

TM: Joe D. Gamble/ED3
Reference OSF 5

Definition of the Earth atmosphere at extreme high altitudes has greatly benefited from the Space Shuttle flight experience. Flight data from the early Space Shuttle entries indicated significant gradients in the atmospheric density profiles in the mesosphere region (approximately 50 to 90 km). Changes in density of 15 percent to 20 percent occurring over altitude increments of less than 1 km were observed on Space Transportation System (STS) mission STS-4. Since advanced entry vehicles such as the aeroassisted orbital transfer vehicle (AOTV) will be using this altitude region for much of their maneuvering, accurate models of the atmospheric density are required. Early design studies of the AOTV have shown a particular sensitivity of the guidance performance to large density gradients occurring over a small altitude variation. It has been difficult in the past to obtain accurate measurements of density changes over small altitude increments near the upper bounds of the mesosphere. Since the Space Shuttle provides continuous accelerometer measurements during its descent, it represents an ideal test vehicle for obtaining high-resolution density measurements.

An activity has been established for obtaining sufficient high-altitude density measurements from the Space Shuttle entries to build a statistical data base that can be used to improve atmosphere models in the mesosphere region. Accelerometer measurements from the Orbiter inertial measurement unit and aerodynamic coefficient identification package are used to derive the atmospheric density along the entry trajectory. These data are compared and correlated to density profiles of various existing atmosphere models and to the profile derived from a best estimated trajectory reconstruction of the entry trajectory. These analyses are being used to help define density dispersions for application in the preliminary design of advanced vehicles, such as the AOTV.

During 1987, Shuttle data from the NASA Langley HiRAP experiment have been analyzed for the ten flights on which it was flown. This data was obtained in the altitude range up to a maximum of 160 km, compared to the accelerometer maximum range of 95 km. Thus, the capability to better define density gradients has extended up to 160 km in altitude. NASA contractor reports covering both the onboard accelerometer and HiRAP data have been written and will be published in January. These reports compare the flight data to current atmosphere models.

An atmospheric data base has been compiled from the first 22 Space Shuttle entry flights (including the HiRAP data) and is available for use on IBM-compatible personal computers. Comparison of these data to existing atmosphere models indicates that the Marshall Space Flight Center's global reference atmosphere model with random perturbations produces density profiles similar to those observed on the Space Shuttle entries. As additional Space Shuttle data are acquired, a statistical model including seasonal and limited latitudinal effects will be constructed and used to evaluate existing atmosphere models further.

Typical Shuttle spring results showing comparisons with remote (◇), GRAM (○), and AF'78 (□).
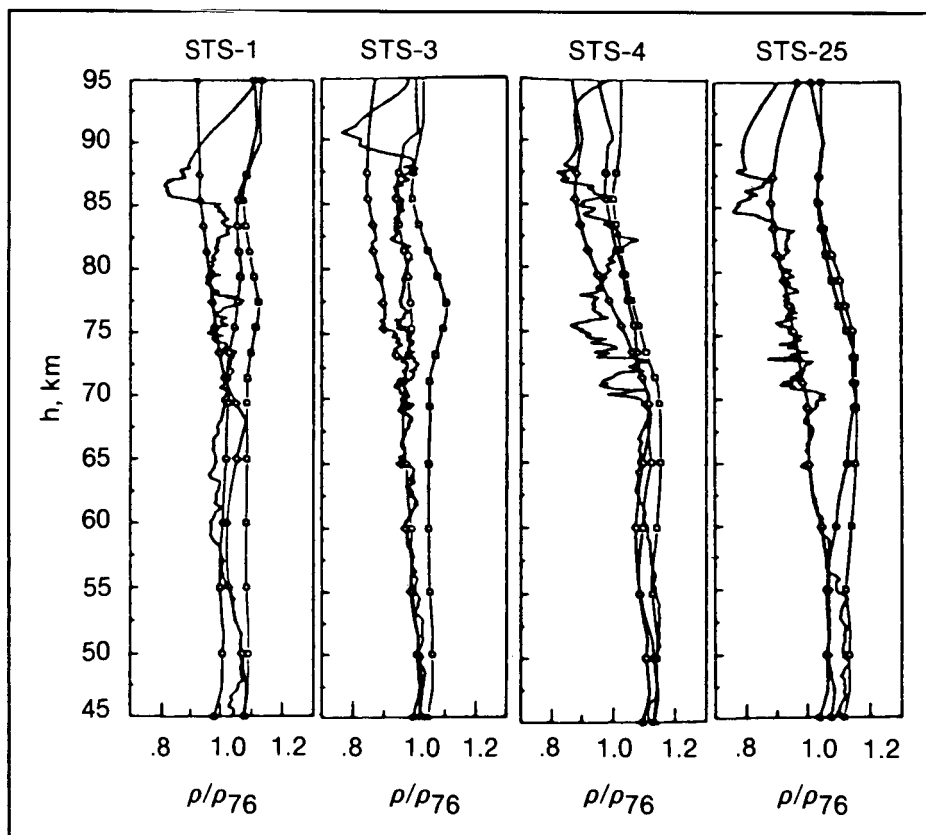
Orbital Debris

TM: **Donald J. Kessler/SN3**
Andrew Potter/SN3
Eugene Stansbery/SN3
Reference OSF 6

As of January 4, 1988, The U.S. Space Command maintained orbits for 7,030 man-made objects in space. This represents more than a 10 percent increase in the number a year ago. The major source of these objects continues to be satellite breakups or explosions in Earth orbit. The explosions have also produced a much larger number of orbiting objects which are too small to be detected by U.S. Space Command ground radars but are detected by ground telescopes and returned spacecraft surfaces (reference Research and Technology Annual Report, 1984, on orbital debris). While U.S. satellites have not been a significant contributor to on-orbit explosions since 1981, satellites from other countries have continued to produce a significant amount of debris. NASA is beginning to work with some of these other countries, as it has been working with U.S. agencies, to minimize the future accumulation of orbital debris.

However, the amount of debris already in orbit has significant design implications for the Space Station, and the need to understand both past and future satellite breakups has both design and operational implications. The size of orbital debris which is most important to the Space Station is about 1 cm diameter. In the past, ground telescopes have been used to obtain data on debris of about this size. However, recent data from the combination of infrared and optical telescopes as well as from ground radar have shown that most orbital debris is much darker than previously believed and that existing telescope configurations can only detect about 2 cm debris. In addition, because of the very restrictive lighting constraints required to observe orbital debris in low Earth orbit, the fragments from many important satellite breakups could not be observed. The telescopes were either located at positions on the Earth where the lighting constraints were not appropriate when the fragments passed over the telescope site or weather was poor when the lighting constraints were good. Consequently, it became necessary to look for another technique to monitor 1 cm orbital debris.

Ground based radars have several advantages over other types of systems, including their ability to operate in nearly all types of weather conditions and at any time

of the day. The U.S. Space Command maintains a catalog of larger orbiting objects, using ground based radars. The information obtained by these radars includes size and orbital elements sufficiently accurate to locate and identify the objects at some later time. By optimizing Space Command radars to perform this cataloging function, only larger orbital debris can be detected. Therefore, a new approach to using ground radar is required to detect smaller debris.

In the past year, a conceptual design for a ground based radar has been developed that is optimized for the detection of smaller orbital debris. This system has been designated the Debris Environment Characterization Radar (DECR). The DECR system would be quite different from radar systems operated by the U.S. Space Command in that it would statically sample rather than catalogue. Several unique design elements result from the statistical nature of the measurement. U.S. Space Command radars typically have very small fields of view (FOV's) which can be rapidly scanned across the sky. Rapid scanning allows the radar to search for and acquire a target while the narrow field of view aids in the accurate determination of orbits. The DECR system design, on the other hand, has a fixed, vertically pointed radar beam with a relatively large FOV. The large FOV allows more objects to be detected, improving the statistics. By holding the antenna beam fixed, more energy is concentrated into the same area of sky than in search radars. Vertical pointing minimizes the slant range to the object.

The DECR system design has also been optimized by choosing wavelength. For a fixed FOV, the optimum wavelength for detection of an object is approximately equal to the circumference of the object. Therefore, for 1 cm diameter orbital debris, the optimum wavelength for the radar system is approximately 3 cm, corresponding to X-band (8 to 12 GHz). This is a shorter wavelength than typically used in U.S. Space Command radars and is a major factor in their inability to detect small orbital debris.

The DECR would be a pulsed radar, with the time delay between the transmitted pulse and the received signal determining the range. Other design elements include the use of a parabolic dish antenna with a multiple horn monostatic feed. Slight differences in signal strength from the multiple feeds are used to determine the direction at which the object crosses the radar beam.

Current plans include procurement of the Debris Environment Characterization Radar to be located at a site near the equator by late 1990. An equatorial site would provide the most complete coverage of orbiting objects since all inclinations pass over the Equator. Several NASA tracking stations, located at low latitudes, which are being phased out by the coming operational status of the Tracking and Data Relay Satellites (TDRS's), have been suggested as possible locations for DECR. These include stations located on Ascension, Guam, and Kauai.

The Debris Environment Characterization Radar provides additional coverage to the U.S. Space Command operational capability.
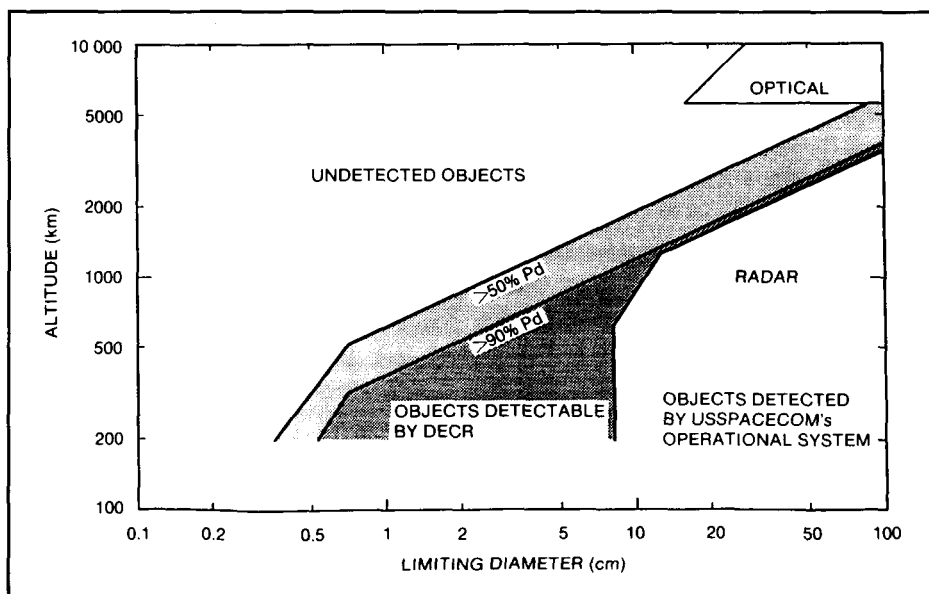
Satellite Services System

TM: Gordon Rysavy/EX2
Reference OSF 7

The fully operational Space Transportation System must meet requirements for a wide range of satellite servicing functions, including capability for payload deployment and retrieval, payload support on sortie missions, and satellite support servicing within or adjacent to the Space Shuttle cargo bay. Potential satellite support requirements include: (1) resupply of expendable items, such as propellants or raw materials for processing; (2) checkout, maintenance, and repair; (3) reconfiguration of sensors; and (4) component exchange.

Previous studies defined the requirements and provided conceptual designs of various items of satellite services equipment. Some of this equipment is now available or under development, and the remainder consists of newly identified items for future development consideration.

The envisioned servicing equipment will be capable of multiple uses on the Space Shuttle, the Space Station, and orbital maneuvering vehicles and will provide services for satellites of wide-ranging varieties and orbital locations. This commonality will be achieved by maintaining standard interfaces, which are being developed in conjunction with the definition and development of the servicing equipment. Based on customer inputs through study contracts and workshops, concepts are defined and given testbed evaluations leading to flight hardware specifications.

The NASA goals are to baseline generic servicing equipment and to standardize the servicing interfaces, thus allowing satellite developers to consider servicing in their original design phase.

Major activities conducted in 1987 include the conceptual design of a versatile, lightweight satellite holding device; the formation of a JSC Satellite Services System Working Group; demonstration of a force/torque sensing mechanism for the Remote Manipulator Development Facility; and a joint NASA/DOD study program called "Space Assembly, Maintenance, and Servicing (SAMS)."

The satellite holding device will be used for the maintenance, repair, checkout, and temporary berthing of satellites during on-orbit operations. It is presently on hold, pending funds for hardware development.

The objective of the Satellite Services System Working Group is to coordinate, focus, and promote satellite servicing through meetings consisting of NASA, DOD,

industry, and international participants. Various action items were undertaken with the following planned publications: Book of Key Issues (September 1987), Servicing Equipment Catalog (March 1988), Customer Cost Guide (March 1988), and Robotic Equipment Status (March 1988). The Force Sensing Electromagnetic Grapple Device is currently being developed as a package for a flight demonstration in the 1989 timeframe. The flight experiment will demonstrate the capability to display forces and torques incurred at the end of the arm. In addition, the ability to align and grapple

with the Electromagnetic Grappling Device will be demonstrated.

The SAMS study effort considered DOD, NASA, and commercial spacecraft and covered all aspects of on-orbit servicing, including requirements, spacecraft design, hardware/tools, mission scenarios, and system analysis. The culmination of this first-phase study will lead to the identification of selected hardware and procedural proof-of-concept evaluations to be conducted in the second phase of the SAMS program.

The Force/Torque Sensing System enhances the Remote Manipulator System capabilities.

REMOTE MANIPULATOR ARM
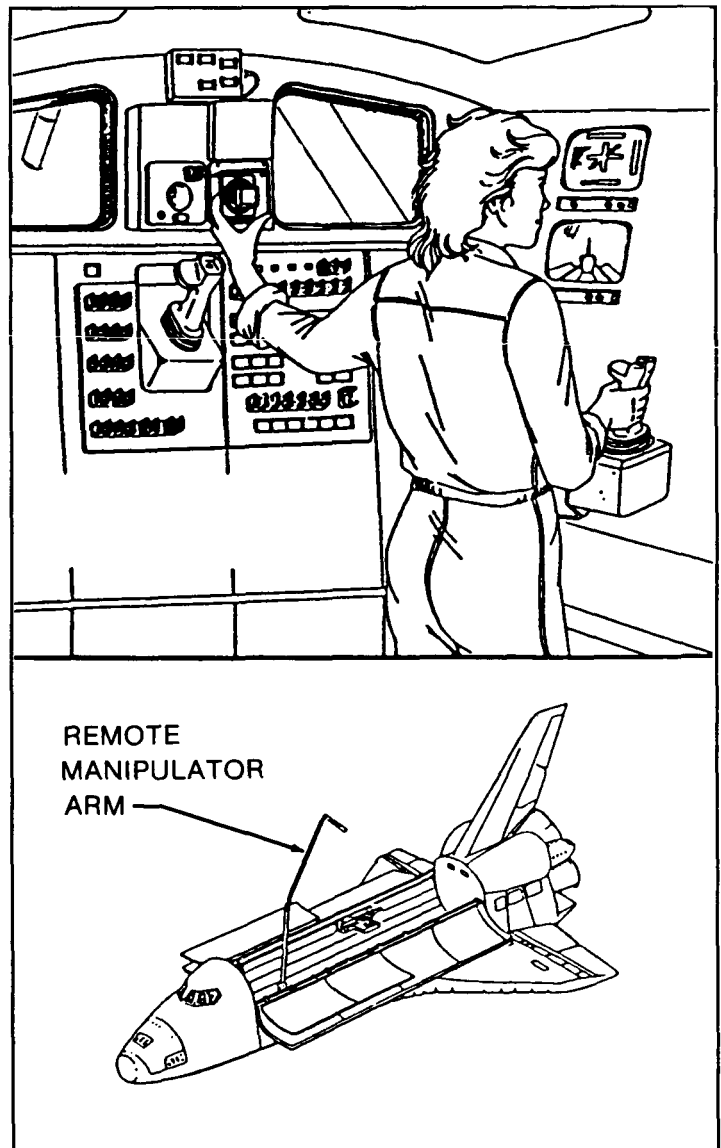
Interactive Control System Design

TM: Edward T. Kubiak/EH2
    Duane A. Johnson/EH2
Reference OSF 8

High-speed interactive graphics can markedly facilitate analysis of complex control problems. Two particularly advantageous applications are multibody proximity operation problems and control system analysis involving sophisticated dynamics, such as large flexible space structures. Analysis assessments which are cumbersome using two-dimensional plots may be readily concluded by the use of three-dimensional dynamic representations. Toward this end, a basic laboratory environment has been established which allows the control system designer to rapidly assess the effect of his design iterations on a complex control problem. Particular hardware includes an IMI-555 high-speed graphics device lashed to a high-speed Masscomp 5600 "microcomputer." The IMI-555 uses stroke (as opposed to raster) graphics with high-resolution (4k by 4k lines) and an exceptional display processor rate (32k vectors at 36 frames per second). The Masscomp 5600 contains dual Motorola 68020 CPU chips and special high-speed floating point circuitry.

During fiscal year (FY) 1987, the first fully operational application was hosted in the laboratory and was heavily utilized. A multibody simulation called Interactive Orbit Simulation (IOS) was installed on the Masscomp 5600 complete with supporting graphics for both the Masscomp "Aurora" monitor and the IMI-555 graphics processor. IOS contains the GN&C for both the Orbiter (high-fidelity) and the Space Station (simplified). The interactive nature of the simulation included the capability to mid-run adjust GN&C parameters as well as to input manual thruster commands in both a rotational or translational three-axis sense. Example problems worked during FY 1987 included preliminary assessments of Orbiter-to-Space Station approach trajectories and analysis of orbital rotational maneuver algorithms. For the trajectory assessments, multi-eye-point three-dimensional scenes were graphically portrayed to provide a quick grasp of clearance and thruster impingement (on Space Station) problems. As the Orbiter approached the Space Station, the effect of the Orbiter's thrusters was vividly displayed on the IMI-555 monitor. Also, a new technique for rotational maneuvers is under investigation for potential Orbiter upgrading and baselining Space Station capability. The existing

Orbiter algorithm has been undergoing performance analysis testing while this new method is being incorporated into the IOS simulation. A preliminary finding on the existing technique was readily detected using three-dimensional graphics; body axes tend to meander during the course of the maneuver, and this is symptomatic of unnecessary thruster firings.

Future efforts will be centered around control system analysis involving sophisticated dynamics. Accordingly, a flexible body simulation named the "Orbit Control Simulation (OCS)" has been hosted in the laboratory. OCS has the capability of modeling connected spacecraft bodies which are both flexible and articulating. Supporting graphics are currently being designed so that state-of-the-art studies in flexible control will further demonstrate the advantages of the interactive graphics approach to analysis.

Interactive on-orbit simulation interfacng with dynamic graphical displays.
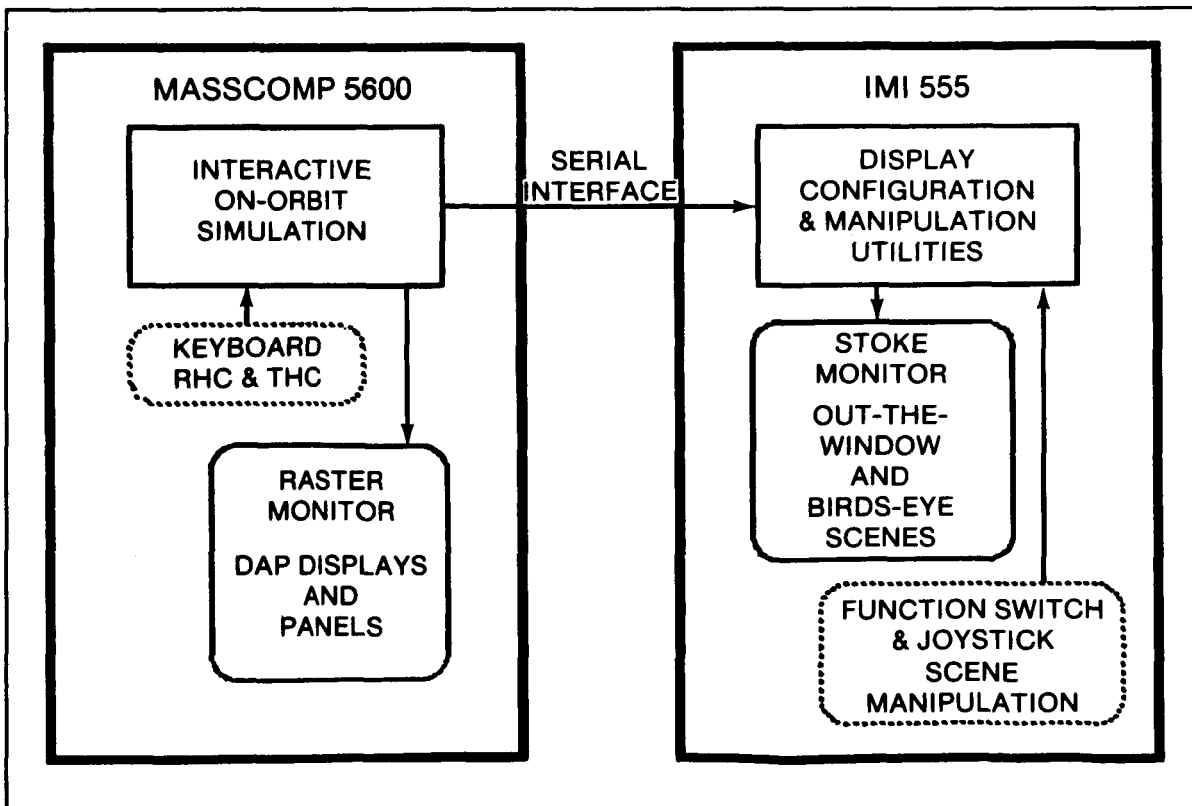
Robotic Vision Tracking Sensors

PI: James C. Lamoreux/EE6
Reference OSF 9

It has been recognized for some time that there are many space-related operations which can be improved with the advent of some form of robotic vision tracking sensor. Many of these operations, which presently rely on an astronaut for manual control and manipulation, can be enhanced in the areas of efficiency, accuracy, repeatability, and safety.

The goal of the Robotic Vision/Tracking Sensors Research and Technology Objectives and Plans was to develop, test, and evaluate a tracking sensor as an aid for proximity operations and "eye-hand" coordination of robotic manipulators during satellite servicing.

The approach was to adapt, extend, and optimize an existing tracking system, developed by McDonnell Douglas Astronautics Company and to integrate this into the Manipulator Development Facility (MDF) at JSC as a proof-of-concept demonstration with the Remote Manipulator System (RMS) arm.

The architecture of the multimode tracking sensor is shown in the first figure. The multiprocessor tracker is composed of three functional parts:

- A Fairchild CCD 5000 camera and video processor
- The MDAC 673 Image and Tracker Processor
- The Z8000 Executive Control Processor

The video tracking functions are computation intensive, requiring a high throughput special purpose signal processor. To match the video data with the bandwidth of the image processor, data compression is performed by the video preprocessor by either excluding regions of the scene that are of no interest or by performing pixel averaging. The preprocessor also performs a tracker-controlled brightness and contrast adjustment to the video image.

The MDAC 673 is a high-speed, special purpose microcodable signal processor. All tracking functions are performed in the MDAC 673. Existing algorithms are (1) correlation (2) centroid, (3) conformal gate,

and (4) guard gate. The correlation tracker is a feature tracker that tracks by finding the best match of a video reference image with the scene. The centroid tracker is a contrast tracker that finds the center of the target exhibiting intensities above or below a controllable threshold. The conformal gate is a statistical tracker that classifies the scene as either background, target, or unknown. This tracker finds the target boundary and maintains the tracker gate size to enclose all of the target. The guard gate tracker detects when the target passes behind obstacles and controls the other tracker's operations while the target is not visible.

The Z8000 executive control processor directs the operation of the multimode trackers, provides operator interface, and controls the responses of either vehicles or mechanisms. The executive processor controls acquisition of the target, monitors each tracker's aimpoint, and can reinitialize any tracker algorithm during engagement. The operator interface is provided through the hand controller and the video monitor mounted on the tracking sensor.

Architecture of the multimode tracker.
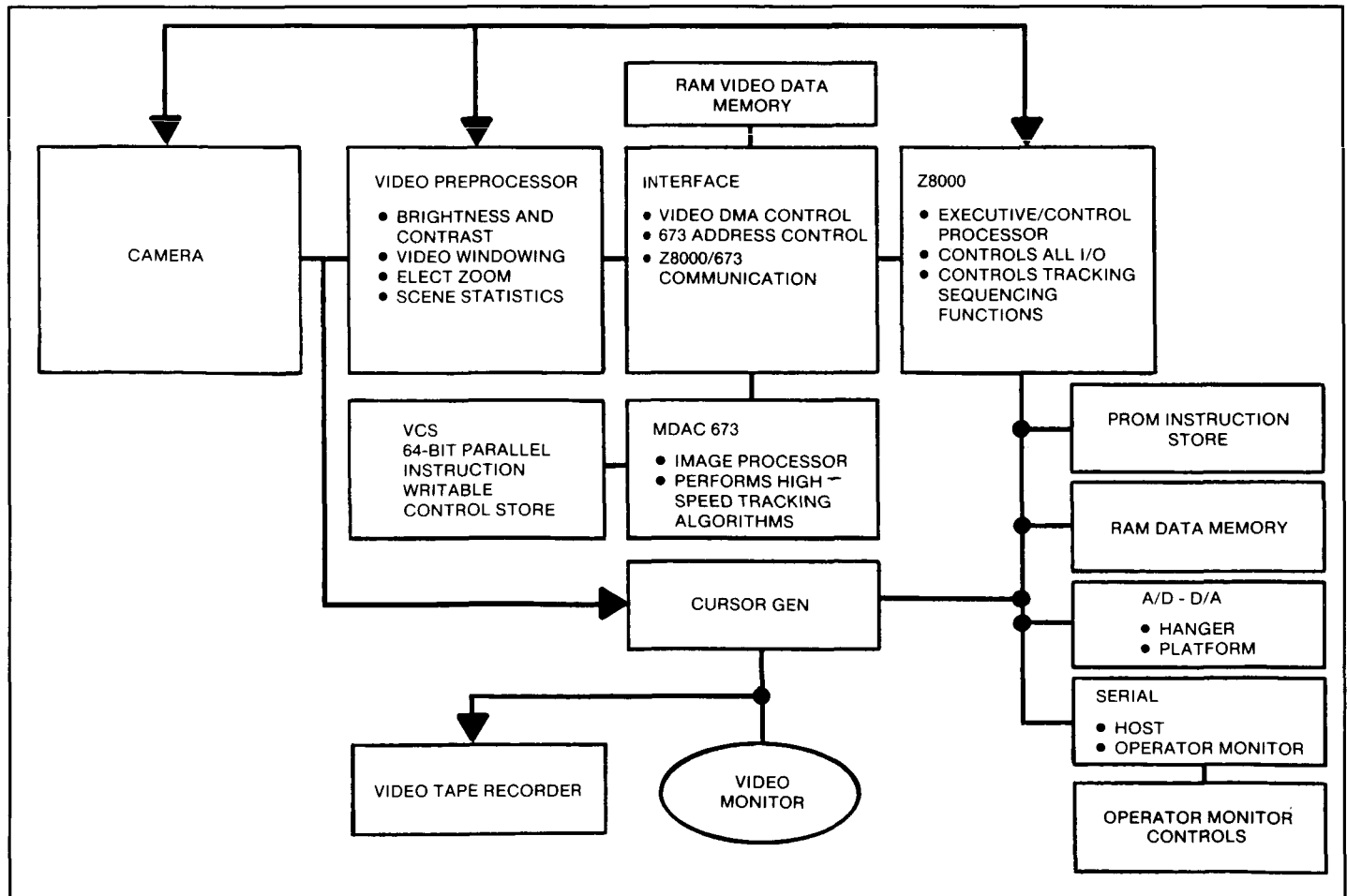
The basic hardware elements and interface for the MDF demonstration are shown in the second figure. The demonstration will use the existing MDF capability and will show the advantages of a tracking aid for maneuvering the RMS arm to a payload target under dynamic conditions. The tracker will be used to process video camera inputs to determine target position, bearing, and attitude and to guide the MDF arm under operator supervision. The tracker will be considered a remote terminal and will input and display target position information and guidance commands to the arm. The demonstration will perform manual target lock-on with autonomous target tracking, MDF arm guidance, approach, and positioning. The target range will be approximately 20 feet, and the target will be stationary for the initial test. After static tests are complete, a series of moving target tests may be performed. Also, close-in positioning with respect to the target will be performed as allowed by the availability of camera lenses and targets.

Target engagement by telerobotic control is also being investigated using a compliant hand, which will incorporate vision-based tracker guidance.

During development of the MDF demonstration, another application for the tracking system evolved and has been worked in parallel. This is a robotic space retrieval system that would utilize a Manned Maneuvering Unit (MMU) with robotic arms and a tracking system for object recognition and guidance commands. An operational version of this concept is depicted in the third figure. This device, referred to as "EVA Retriever", would respond to voice commands to locate and acquire an identified object that was adrift in space, such as a dropped tool or a disabled astronaut, and guide the Retriever to within grappling range of the robotic arms.

To provide for ground-based laboratory evaluation, the tracking system has been mounted on a Cybermation Robotic Platform, as shown in the fourth figure. Target identification algorithms for both EVA Retriever and MDF-type targets have been incorporated into the tracker software. Guidance commands that would normally be sent to the MDF computer or to the EVA Retriever MMU can be routed to the Cybermation platform, and operational simulations of both demonstrations have been performed in the Tracking System Test Bed Laboratory at JSC.
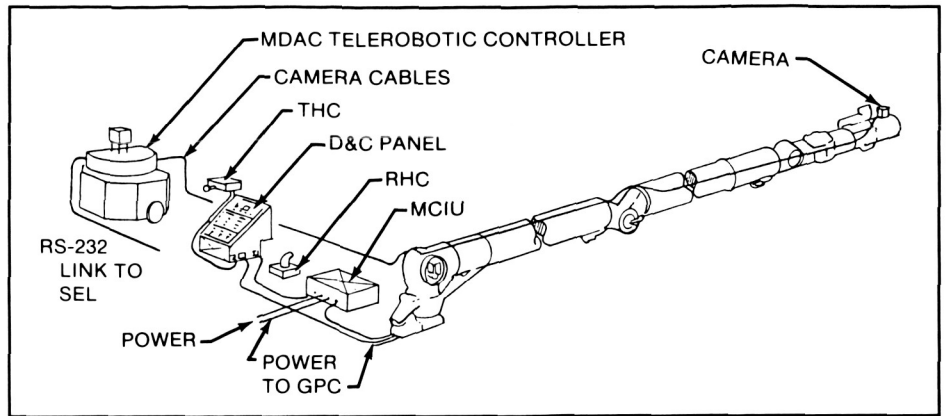
MDAC telerobotic controller/MDF arm interface.
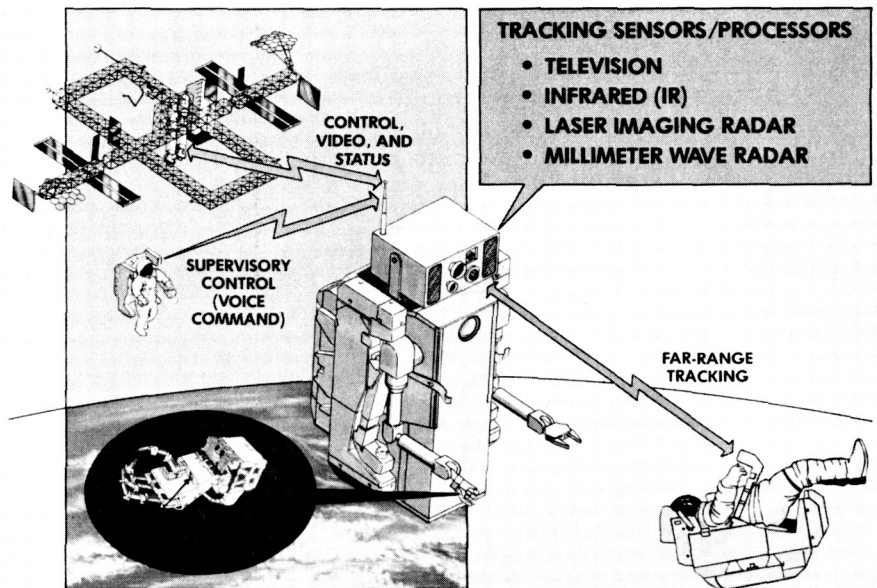
Extravehicular activity retriever.

Tracking system mounted on a Cybermation Robotic Platform
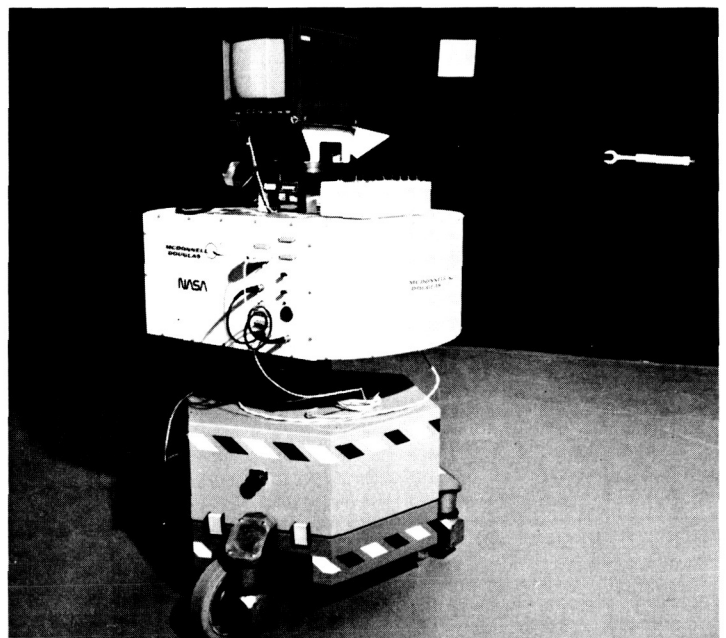
Data and Software Systems Commonality

PI: R. G. Musgrove/EH6
Reference OSF 10

Early NASA research and development endeavors, like Apollo, tended to be one-of-a-kind spacecraft that were primarily engineering demonstrations—stepping stones to new capabilities. The Space Shuttle and Space Station bring a new era of operations, having long life cycles, spanning decades. Within this context of large-scale evolutionary flight programs, "commonality" is the attribute of planned sharing of system resources. The shared resources include facilities, culture, instrumentation, tools, methodologies, and system components. This concept is illustrated in the first figure.

The reuse and maintainability of flight hardware and software systems for long-term, evolving flight systems can help reduce costs, improve quality and reliability, and simplify operations. The Data and Software Systems Commonality Research and Technology Objective Plan (RTOP) has its goal to serve as the catalyst to coordinate commonality approaches across flight programs.

The Data Systems and Software Commonality effort in 1986 conducted a comprehensive survey to determine potential commonality initiatives and approaches. A three-day workshop was held at JSC to specifically address the need for commonality and the issues associated with standardization and management. The workshop was well-attended and served to focus agency attention on commonality. The results of the workshop are published in two volumes (JSC-22469).

The commonality workshop identified many commonality initiatives that have been underway on a local basis within a number of the NASA programs or centers. Workshop participants identified many commonality needs, lessons learned, issues, and recommendations. The conclusions from the workshop state that commonality is clearly attainable in many situations, but "practical strategies for commonality need to be developed that can be embraced by diverse programs and projects."

The commonality effort in 1987 focused on developing preliminary commonality concepts and providing a catalyst for the establishment of management and organizational elements to promote commonality in flight computing systems. The results from the commonality workshop were analyzed, translated into candidate scenarios for agency implementation, and presented to major program offices. Support for the proposed commonality initiative was found in the Office of Safety, Reliability, maintainability, and Quality Assurance. An interprogram working group was convened to develop detailed commonality approaches and to aid in assessing the scope of such an endeavor.

The working group met for two days, discussing the needs, scope, issues, and incentives related to avionic systems commonality. The following summarizes the main conclusions resulting from this activity:

Commonality means sharing relevant, kindred features, with opportunities for commonality occurring in all aspects of software systems. Commonality is a means, not an end; optimal commonality is the proper goal. A commonality program must address both resources and infrastructure, since commonality is a continuing open-ended process.

The working group defined 30 tasks that will aid in promoting commonality in flight avionic systems. These tasks were detailed, resources scoped, and their interrelationships identified. The tasks focused on needs in management infrastructure, communication and training, data base information, systems interfaces, avionic applications and subsystems, methodologies and models, and standards and guidelines. A five-year task schedule was developed to provide a view of the potential scope of such a program.

It is not recommended that these tasks be implemented carte blanche. Instead, an evolutionary and bootstrap approach, shown in the second figure, is proposed as a practical way to implement the program. The phased implementation approach proposes to establish a nuclear infrastructure to provide the support for the effort, to proceed to capture enabling and existing resources that will provide the initial commonality infrastructure, and then to pursue the implementation of an operational infrastructure as appropriate.
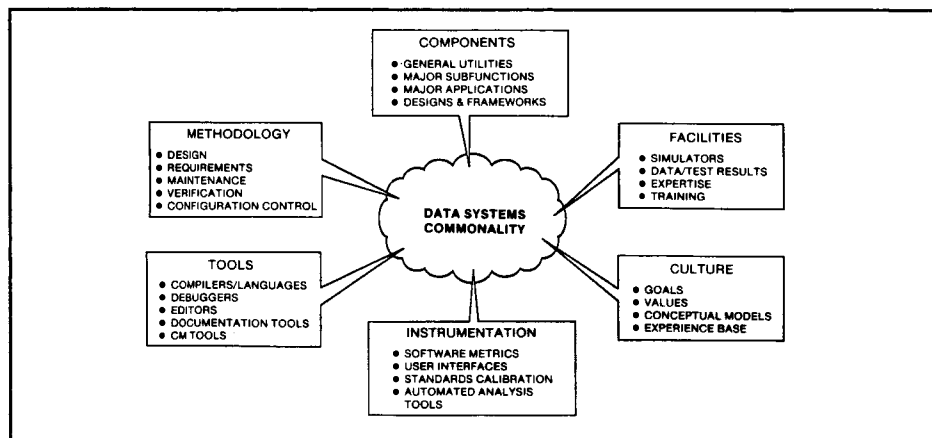
"Commonality" means sharing resources.

An evolutionary, bootstrap approach is needed.
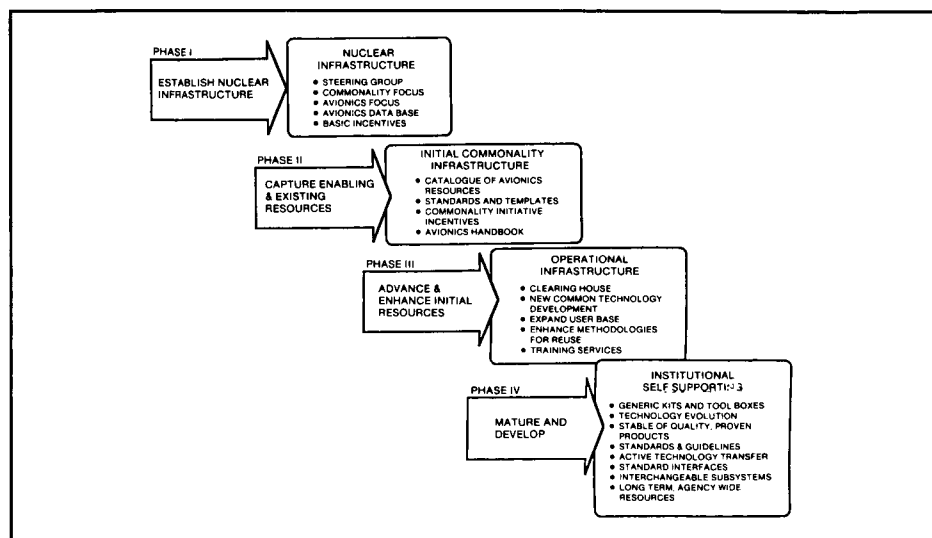
Automated Software Development Workstation

PI: Robert N. Hinson/FM75
Reference OSF 11

In the fall of 1985, an Automated Software Development Workstation project was initiated by the Johnson Space Center through a contract with Inference Corporation to explore knowledge-based approaches for increasing software productivity. Automated generation of target language code from an end-user's program design description was an eventual goal. Since speeding up conventional software development processes had shown only a moderate payoff, reuse of existing software designs and components was viewed as the only viable way of addressing this problem. Initial activities of this project focused on the development of a computer-aided software tool set for cataloging software components and designing software using those components. The heart of this tool set was an interactive graphical design editor, which used a dataflow specification language for design editing and components composition, supported by a rule-based expert for assisting in the reuse design process. The components catalog was composed of a set of Fortran routines which had been used in the construction of orbital simulations. It was recognized early in the project that the area or domain of interest would have to be restricted in order to deal with extreme complexity of a typical software system. This restricted approach, thus, became the basis for what was termed as a domain-specific automatic programming system.

The functionality and performance of the prototype of this project was adequate to demonstrate the applicability of this approach to software development for complex applications. However, the experience of building the initial system led to the conclusions that (1) domain analysis and design are very difficult, and (2) domain-specific systems can be quite useful within the domain of application, but the range is often very narrow. It was, therefore, concluded that these two issues must be addressed if domain-specific automatic programming was to play a significant role in future software development environments.

The first phase of the Automated Software Development Workstation was completed in December of 1986. Phase two of this project was subsequently started and was focused on the three bottlenecks that were observed during phase one. These bottlenecks were (1) developing a domain language, (2) describing design refinements and constraints, and (3) describing the generation of target language code from a sufficiently detailed program description. It was decided by Inference Corporation that reduced effort could be spent on each of these three tasks by automating the programming knowledge acquisition process and by using an object-oriented development methodology at all stages of the program design process.

Inference proceeded in 1987 to develop a strategy for implementing these ideas and published a paper describing the details of its approach in the Proceedings of the Space Operations Automation and Robotics Workshop, Houston, Texas, August 1987. In addition, Ada was chosen as a new target language for two reasons; (1) the Space Station had selected Ada; and (2) Ada offered a better transition from an object-oriented program design.

During the rest of fiscal year 1987, implementation of the above strategy was initiated. The problem-solving architecture and the basic knowledge acquisition algorithms were designed and implemented, and the target language reusable components library was selected and installed. An initial version of the Ada components cataloging subsystem, including the user interface, was completed and work began on initializing the catalog. An initial pass was made at the specification of the application domain for a prototype demonstration.

The ultimate goal of this project is a production-quality system that could be described an an "application generator generator"; that is, a knowledge-based environment for the construction of special-purpose systems for the generation of applications software by the end-user within the domain of his interest. It is also intended that this project will result in the enhancement of the Space Station Software Support Environment with the appropriate transfer of technology.

Automated Software Development Workstation architecture.

90 OSF

Development of Advanced Graphics Lab Applications

PI: Gunter Sablonski/FM7
Reference OSF 12

The effective utilization of state-of-the-art graphics systems requires a considerable learning process for engineering personnel. To date, this process has resulted in many engineers not utilizing these systems for engineering analysis and, thus, not accessing a technology that would expand their engineering capabilities and productivity.

The goal of this RTOP was to develop a high-level, intelligent user interface which would alleviate the user knowledge acquisition problem with graphics systems. This development expands the capabilities of the existing prototype user-friendly interface to lead toward the goal of a graphical visualization programming system.

The intelligent graphics generation process, as illustrated, begins with the user constructing a graphical tree consisting of objects and cameras to be simulated. The user specifies object state data through the interface, which then saves this information in a tree library. Graphics code is then generated, compiled, linked, and executed in parallel with the user simulation. This process conforms to requirements of rapid prototyping, and therefore, the user can easily reconfigure the graphics scenario as desired.

During the term of this project, several key tasks were accomplished which enhanced the prototype significantly. A preliminary task was to implement a UNIX tool called Yet Another Compiler-Compiler (YACC) to be coupled with the lexical analyzer, LEX. These integrated tools resemble an expert system in that there is a defined rule base and a simple inference engine which allow the graphics expert to embed knowledge into the system. When the system is accessed through the user interface, these rules are invoked, generating graphical source code resulting in code which is targeted for a specific graphics device. When coupled with a user data base or simulation, this software provides an engineering analysis visualization tool.

The enhanced low-level user interface was ported to graphics systems such as the IMI, GTI, and IRIS 4-D. In addition, code generation software was developed for these systems through which users can now easily manipulate the hierarchical relationships of graphical objects in real-time.

A prototype intelligent motion generator was also developed for engineers who want to enhance analysis of simulated scenarios. This motion generator provides a high-level interface for ease of understanding, spline interpolation for uniform motion, tree modifications on the fly, and simulation data compatibility.

This software tool incorporates an object-oriented design methodology. Written in the programming language, "C", it allows portability with extensive in-line documentation, resulting in ease of understanding. Another significant result of this software development is that the rapid prototyping capability reduces significantly the cost of developing new software. Additional users' requirements can easily be embedded into the expert-like system with a time-cost factor considerably lower than traditional software development resources.

In summary, the significance of these developments are important in engineering visualization. The productivity of users who require graphics as an enabling technology can now be increased significantly. This approach to utilization of graphics systems will prove to be the state-of-the-future for graphics software systems. Continued development of this project will result in a visualization programming tool which will have impact not only within NASA but within the commercial world as well.

Intelligent graphics generation process.

Advanced Space Flight Simulation Technology

PI: H. K. Hiers/EF5
Reference OSF 13

Analysis of advanced program requirements in the area of expert systems identified several high-potential areas for further investigation. Primary among these was expert systems that operate in a real-time environment and interface with flight crew and/or flight subsystems. Rendezvous operations were chosen as the focus for a development effort. In 1986 a prototype rendezvous expert system was developed and demonstrated. This prototype addressed selected portions of a rendezvous maneuver and was integrated with custom-built simulation of the Space Shuttle, its subsystems, and the Space Station.

In fiscal year (FY) 1987, the Rendezvous Expert System (REX) was enhanced and modified for integration with the Systems Engineering Simulation (SES) Laboratory, a major real-time engineering simulation facility at JSC. The SES is used extensively for real-time engineering evaluation of advanced concepts and for on-orbit procedures development and flight crew familiarization, and thus, provides an excellent environment for engineering evaluations, procedures development, and crew familiarization with a real-time expert system integrated in an appropriate and realistic environment.
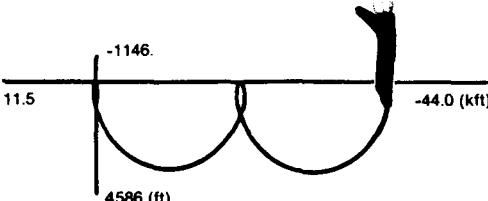
Initial efforts in FY 1987 focused on the formal definition of requirements for the REX. It was decided that greater advantage should be taken of currently established Shuttle rendezvous procedures. These rendezvous procedures have been extensively refined and revised over a period of years at JSC, and they incorporate the results of hundreds of Shuttle rendezvous simulations. Furthermore, these procedures are extensively documented and well-understood by the flight crews. They also include the requirements for the ground flight controllers that monitor and assist the flight crews during actual rendezvous flights. Therefore, it was considered important to implement these procedures within the REX. The Shuttle flight crews and other rendezvous experts have endorsed this concept.

Requirements for enhancements of the SES for integration with the REX were also defined. (An important advance over the prototype system, as mentioned, is the real-time interface with the SES, which simulates Shuttle flight dynamics). In addition, the crew interface with the REX was defined and is provided by a CRT and a control device (mouse) installed in the SES Space Shuttle aft cockpit.

Following the definition of requirements, design and development of the software was initiated. Implementation activities included the REX data acquisition module and data filtering software. The latter ensures that only meaningful data from the SES is passed to the REX knowledge base to prevent excessive and repetitious rule firings. A stand-alone verification tool was also implemented and is being used extensively to verify iterative software development. Rules governing continuous monitoring of Guidance, Navigation, and Control sensors were designed and implemented. Rendezvous procedure execution rules were also designed and are under development. Modifications to the SES were also implemented. Completion of the basic integrated system is scheduled for the second quarter of FY 1988. Depending on resource availability, enhancements of the basic system will continue throughout FY 1988, and crew familiarization of real-time expert systems will begin.

Information as displayed by the Rendezvous Expert System.

GMT: 157.44				MET: 157.44		
SYSTEMS STATUS	REND	PROK OPS		MONITOR	CONTROL	REL MOTION
SYSTEM HEALTH AVAILABLE? IN USE?	REND PROCEDURES	GROUND	ONBOARD	REL MOTION		

SYSTEMS STATUS:
NAV
YST — YES
ZST — YES
COAS — NO
RR

REND PROCEDURES:
12 REND NAV ENBL
13 ROT MNU TGT TRK
14 ST TGT ACQ
15 ST NAV MONITOR
16 END ST PASS
17 NAV FILT RSTRT

GROUND: 27 NC, 28 NH, 29 NSA, 30 NPC, 31 TIDL
ONBOARD: 32 NCC, 33 TI, 34 MC1, 35 OOP, 36 MC2, 37 MC3, 38 MC4

REL MOTION: -1146. 11.5 4586 (ft) -44.0 (kft)

SYSTEMS MALFUNCTION DATA	STOP AT	DELETE	IGNORE	CONTINUE

SYSTEMS MALFUNCTION DATA:
YST: FAIL: THE -Y STARTRACKER DATA-GOOD FLAG IS FALSE
RR: FAIL: THE RR RANGE AND ANGLES DATA- GOOD FLAGS ARE FALSE

PROCEDURE DATA WINDOW 1

		-Z	-Y	-ZBS
RECOMMENDED		-Z	-Y	-ZBS
ACTUAL		-Z	-Y	-ZBS

A: UP: TGT ID: 1
B: UP: BODY VECT: 3 6 6
C: UP: PITCH: - 0 87.7
D: UP: YAW: - 280.6 358
E: UP: OMICRON 0 90 0
F: C3: DAP-B/AUTO/NORM
G: UP: MNVR TRK: ITEM 19 EXEC
H: UP: VER MNVR COMPLETE:
I: C3: DAP-A/AUTO/VERN

PROCEDURE DATA WINDOW 2

Optical Communication Systems

PI: Joseph L. Prather/EE64
Reference OSF 14

Several applications of short range, non-line-of-sight infrared communications were investigated, including multi-user, multi-access voice/data communications, biomedical data links, robotic control, and magnetic end effector data transfer. In addition, laser communication techniques for use between low Earth orbit vehicles and geosynchronous satellites were analyzed. Finally, the use of fiber optics to provide high data rate links between the Orbiter flight deck and the payload bay was investigated.

Laser communications hardware, which will provide a one-way optical video link between a mobile platform and a stationary base unit, is being developed. The hardware will also provide optical tracking of the mobile platform to maintain a line-of-sight communications link. The system (which will be used to determine the problem areas in providing a low Earth orbit to geosynchronous Earth orbit laser communications link) is in the final stages of development and will be ready for testing and demonstration in March of 1988. A proposal for a flight experiment between the Orbiter and the Advanced Communications Technology Satellite was developed and submitted to headquarters.

A flight experiment was defined and approved, and preliminary work to determine potential problem areas in using fiber optics in a space environment was completed. Many samples of various types of fibers were thermally cycled to determine the effect, and a report was generated.

A study is continuing to determine the best total system design to use for a given infrared communications application. The application will determine which parameters are most important to the design (i.e. coverage, signal-to-noise ratio, DC power consumption, cost, and complexity). The study includes the most favorable transmitter and receiver designs, filtering types, and modulation and demodulation techniques to be used, based on low, medium, or high data rates.

A design is being developed which will provide a two-way communications link between a computer and a robot. The link will include a man-machine interface via voice recognition and synthetic voice feedback. Applications for this technology include robotic tenders in a space environment and control of guided vehicles in automated warehouses. The system will be

demonstrated in March of 1988.

A two-channel, one-way infrared communications link was designed, developed, and tested in-house. A contract for a system using digital techniques and providing four biomedical data channels will be completed in January of 1988. This technology has applications in any area, space- or ground-based, where the intent is to unobtrusively monitor physiological functions (i.e., life flight helicopters, operating rooms, and Space Lab).

A system is being developed for demonstration in January of 1988 which will transfer medium data rate information between the end of the Orbiter remote manipulator arm and any target, (e.g., a satellite). The system is now being modified to remove data jitter.

A study is continuing to research other possible applications for optical communications and to determine the state-of-the-art in active development efforts. In addition, the availability of flight qualified or qualifiable optical components or subsystems is being investigated.

Infrared robotics control.
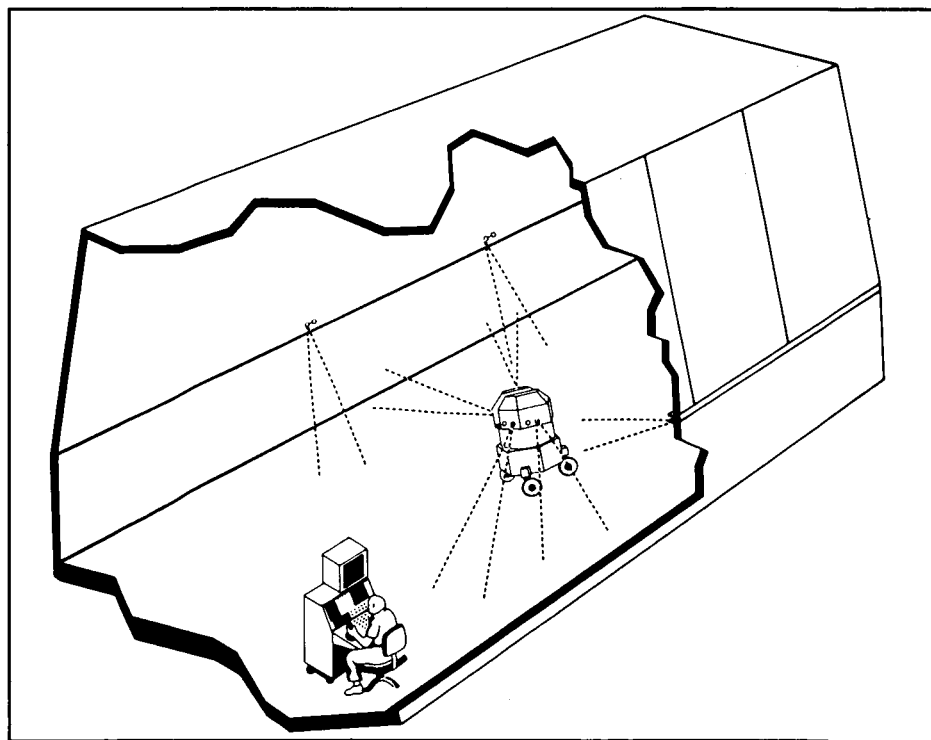
Ada-ART: Specification for an Ada-based State-of-the-Art Expert System Construction Capability

PI: Robert T. Savely/FM72
Reference OSF 15

Expert systems are computer programs that emulate complex human expertise in well-defined problem domains. Software techniques for modeling this type of expertise in a computer program are well-developed. Since certain characteristics of all problem solving methods are generic, they can be separated from the knowledge specific to the problem and used to create a tool for building expert systems. Expert system tools are designed to provide a base for storing specific information as well as being a mechanism for applying the knowledge. The typical tool has many parts, including an inference engine, a user interface, and a structure for representing information.

Although they have reached a point of high commercial visibility, expert systems were originally developed in artificial intelligence (AI) research environments. Most of the available tools still work best in such environments. These environments typically utilize special hardware, such as LISP machines, and relatively unfamiliar languages (at least within science and engineering communities) such as LISP or Prolog. However, the vast majority of NASA and DOD applications require integration of an expert system with conventional software on conventional computers. This has proven to be difficult with existing expert systems tools in the LISP language.

The ART (Automated Reasoning Tool) language or tool for expert system development is a state-of-the-art tool with several methods for representing knowledge. ART is an extremely productive computer language that allows a programmer to develop an expert system in days that would normally take months or that may not even be feasible in procedural languages, such as Fortran. ART was developed in and operates in the LISP language. The goal of this project is to redevelop the ART tool in Ada to allow the use of ART in the cost effective Ada environment.

This work was performed by the University of Houston-Clear Lake and the Inference Corporation. The primary objective of the project is to establish the feasibility of a language in Ada for the construction of expert systems.

This language must be implemented in the Ada™ environment and must possess the following characteristics:

- The language will be Ada-based
- The language should support
  - forward chaining rules
  - backward chaining rules
  - object oriented techniques
  - hypothetical reasoning
  - call outs to Ada modules

The primary goals of the AdaART project are:

- To specify the design of an ART dialect which will deliver ART to Ada programming environments.
- To specify an implementation strategy and a high level technical and management plan for the accomplishment of the implementation effort.

Additional major goals are to develop an implementation and strategy for an Ada-based expert system tool that would

- Conform to proper Ada design and development standards.
- Be amenable to verification and validation standards by independent quality assurance organizations.
- Produce expert systems sufficiently efficient to be deployed in real-time embedded systems.

The work accomplished in fiscal year 1987 included a feasibility evaluation and the generation of a work plan in order to accomplish the goals of this project.

In order to smoothly integrate ART into the Ada environment, a new ART dialect, AdaART, has been specified. AdaART will restrict some of the detailed features of ART. However, it will support the ART functionality and satisfy the goals of the project. The AdaART system will be written directly in Ada. It is proposed that AdaART be developed initially for Ada on the Digital Equipment Corporation's VAX computer architecture.

The construction of AdaART will be executed as three subsystem development efforts. The timeline for each subsystem includes detail module design, coding, and unit testing. The first of these subsystem efforts will develop the Rule Compiler. This component translates the application definition specified in the AdaART language into a combination of Ada source code and related data structures. The second construction effort will build the Runtime Support System. This component provides the basic inference engine for application execution. The final subsystem consists of a set of utility functions which will be used by both the AdaART system and by the applications built using AdaART. Integration testing will begin early during the construction activity. Modules within each subsystem will be integration tested, followed by testing across subsystems. A separate functional organization will have responsibility for quality assurance testing of each subsystem, and finally, the entire product.

The players in expert systems development.
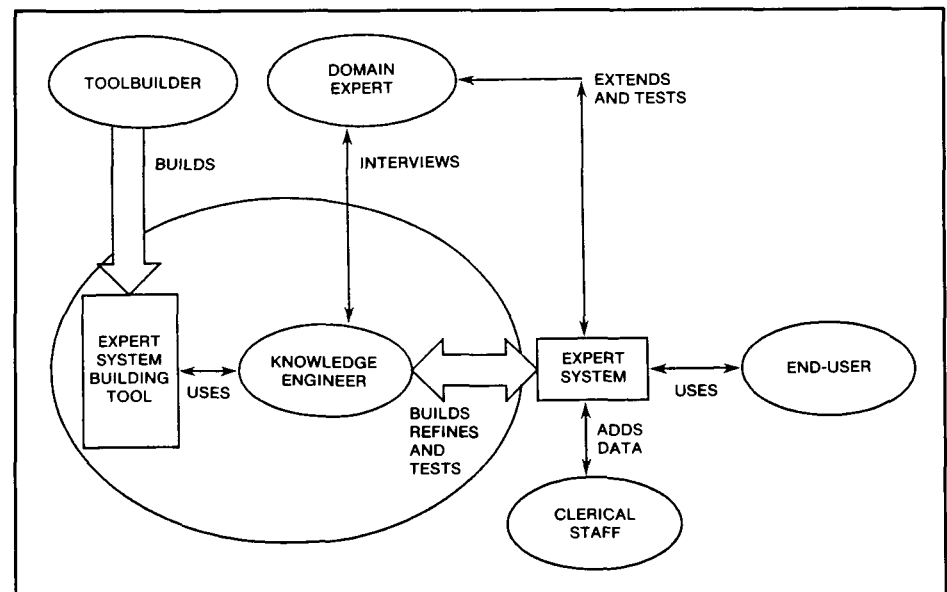
Advanced Mission Cost Model

TM: Kelley Cyr/BX24
Reference OSF 16

This task is intended to develop a state-of-the-art cost estimating model for future space program initiatives. The purpose of the task is to develop tools to support conceptual design and strategic planning studies. Development work is being done on cost modeling, data base enhancement, a designers' catalog, cross-cultural studies, and software development.

The overall objective is to develop efficient tools for estimating the cost of future NASA programs. The tools must be accurate, highly adaptable, robust, and easy to use. The primary tool being developed is a general-purpose cost estimating model. Unlike past cost models which have focused on specific types of spacecraft, the new model will be adaptable to many different kinds of space hardware. It will also take into account technologies and evolving programmatic trends. The model will be able to produce reliable cost estimates, even when the design information is sketchy.

In order to develop the kind of cost model described above, it is necessary to have substantial amounts of data on the cost of past system developments. The data base includes information about all types of spacecraft, launch vehicles, and ground systems developed for both military and civilian applications. In order to support analysis of the more exotic advanced missions, the data base will also include cost data on Earth-based systems that are more analogous to future missions than to previous NASA programs.

The designers' catalog will be a repository of system design studies that have been performed in the past. Information will be stored in such a way that planners can browse through the catalog and find conceptual designs for hardware that meets their needs. Estimated cost and schedule data will be immediately available.

The cross-cultural study addresses the question of why space systems cost much more than other high technology systems, such as airplanes or race cars.

The glue that binds everything together is the application software being developed to automate the routine tasks of storing and analyzing data and preparing cost and schedule estimates. Using state-of-the-art software and hardware, comprehensive resource plans can be developed in a fraction of the time previously required. Trade studies and what-if assessments can be made in minutes rather than days.

The application of advanced mission cost modeling can be seen in the recent study of a reduced cost Space Station. The study required cost estimates of a half-size Space Station in approximately two weeks. Since the turnaround time was too short for conventional cost estimates, an approach was devised that used a system-level cost estimating relationship. The results were that only nine percent of the total program cost could be saved by eliminating half of the Space Station hardware.

By participating in a variety of planning meetings, studies, and workshops, the personnel involved in this task ensure that NASA objectives are supported. This activity directly supports the JSC goal of developing critical technologies and capabilities necessary for the conception, design, development, and operation of systems related to space transportation and exploration. It also supports the JSC objective of developing project management systems which will function effectively and efficiently in a multiprogram environment.

Earth-to-orbit vehicle.

Autonomous Ascent Guidance Development

TM: A. Bordano/FM4
Reference OSF 17

A major national effort is currently underway to develop a mixture of new space launch systems which will meet the demand for placing payloads in Earth orbit in the 1990's and beyond. These future launch vehicles have a requirement for an order of magnitude reduction in total life-cycle costs compared to today's systems. Experience acquired on previous launch vehicle programs over the past 30 years has proven that the recurring flight-to-flight vehicle operating costs play a significant, if not dominant, role in the overall launch cost model. It is quite reasonable, therefore, to expect that investments made today in technology to support efficient, routine vehicle operations will produce substantial payoffs in terms of greatly reduced life-cycle costs for future launch vehicles. This does not suggest, however, that vehicle operations can be completely removed from vehicle design. On the contrary, the two are closely coupled and must be effectively balanced against the overriding issues of flight crew safety and vehicle reliability. The Autonomous Ascent Guidance Research and Technology Objective and Plan (RTOP) was activated in fiscal year 1987 with a goal of exploring technology developments in the field of launch vehicle ascent guidance that show promise of reducing life-cycle costs while supporting enhanced crew safety and vehicle reliability.

As the title of the RTOP implies, one approach for achieving the stated goals for next-generation launch systems is to build-in autonomy. During the past year, several important avenues of research have been pursued toward this objective. Among them are a review of current Shuttle ascent guidance techniques, a survey of new developments in sensing systems technology, a study of the various constraints impacting autonomy, and an investigation of different concepts for automating the vehicle ascent guidance function, including the abort monitoring and retargeting tasks.

The review of current Shuttle ascent guidance techniques centered on the open-loop first stage guidance design. This function is active from liftoff through solid rocket booster (SRB) separation and must successfully guide the vehicle in the most demanding Shuttle flight mode: powered flight through the atmosphere. Focusing on this one aspect of the Shuttle operation uncovers a host of research areas to be explored. The first stage trajectory design requires a large scale flight planning activity on the ground that must begin approximately 1 year before launch. The flight profile is based on mean atmospheric conditions with large margins added for vehicle and environmental dispersions, which severely limits vehicle performance and launch probability. Although some advances in vehicle autonomy have been made, such as the adaptive guidance and throttling (AGT) capability for SRB burn rate dispersions and the adaptive retrim for main engine-out conditions, much work remains to be done before a process like the one conceptualized in the figure can be realistically implemented.

Relieving the restrictions placed on atmospheric ascent by uncertainties in the flight environment was the motivation behind conducting a survey of new sensing systems technology developments. Efforts in this area included understanding the NAVSTAR Global Positioning System (GPS) and how the precise position and velocity information obtainable with this technology may find application in a future ascent guidance system. Advancements in vehicle attitude knowledge were found to be available in ring laser gyro (RLG) and fiber optic gyro technology. Progress in atmospheric data sensing capability was noted in the Shuttle Entry Air Data System (SEADS) and doppler radar wind profiler technology.

While improved sensing systems will undoubtedly lead to more autonomous vehicles, it is also necessary to understand the underlying constraints which will limit the degree to which autonomy can be achieved. In this study, ascent constraints impacting autonomy were categorized in three groups. These are design architecture constraints, trajectory constraints, and operational constraints. Design architecture constraints are those imposed by system design requirements which affect the basic vehicle configuration itself, such as two-stage versus single-stage or solid propellant motors versus liquid. Trajectory constraints are those which limit the allowable paths that can be flown, and thus, force non-optimal trajectories, such as communication and tracking coverage or range safety impact envelopes. Operational constraints are limitations on the launch vehicle handed over from the design phase and essentially are problem areas that are not completely resolved during initial development and testing. Lack of knowledge of actual vehicle performance capability or undersized onboard computing capacity are examples of limitations that impose operational constraints.

The need to reduce the impact of constraints on autonomy makes adaptable, generic guidance algorithms very attractive for use in onboard systems. During the past year, this area of research examined the feasibility of numeric closed-loop first stage guidance algorithms in which the ascent constraints are inherently modeled. Supporting this approach was a study in abort priority guidance and retargeting, which would allow continuous update and monitoring of vehicle abort options. Day-of-launch systems for determining guidance constants near launch time were also investigated. Plans are now being formed to develop a guidance system test bed next year which will link together several computer simulation programs and allow integrated trade studies to be conducted.

Conceptual "realistic" system.

Strategic Planning for a Lunar Base

TM: Barney B. Roberts/ED1
Reference OSF 18

As a matter of future space preparations, NASA JSC has been investigating various options for the future goals of the civil space program beyond that of the Space Station. The strategy of this initiative is to carry out a project which demonstrates U.S. intentions to systematically develop space for scientific, commercial, and humanistic purposes. Of the options considered, the one option with the largest and most influential advocacy has been the proposed manned lunar base concept. For the past several years, JSC's Advanced Programs Office has been involved in the conceptual definition and design of a manned lunar base. The strategy that has evolved over a four-year period of study is one of phased developments. This phase-development approach allows consolidation

of the current phase efforts and the development of an experience base that will increase the probability of success at the subsequent phases. In addition, this approach will also permit the political process to revise goals and objectives at the branch point of each phase and modify the future paths of the lunar development.

As a result of a technology survey of the current state-of-the-art capabilities together with a high level of confidence in future expectations, the proposed lunar base program can best be subdivided into several phases, as briefly depicted and illustrated in the chart.

Phase I: Mid-1990's to 2000: Robotic exploration and site selection.

This phase of lunar development is dominated by orbiting spacecraft and robotic surface vehicles whose purpose is to develop a data base of lunar environments,

resources, and engineering parameters that aid in selection of the site for the lunar base. The capabilities of these "precursor" systems include topographic mapping of the lunar surface, resource assessments, sub-surface data acquisition, sample return, gravity maps, seismic data acquisition, and robotic surface surveys.

To enable the capabilities, or functions, needed at each phase, the analyses have determined that new systems need to be developed and placed into service. For phase I, the current Space Shuttle or possibly even existing expendable vehicle options are suitable for Earth-to-orbit (ETO) delivery; however a new high performance, shuttle-compatible upper stage will be required.

Proposed Lunar Base Program.

NOTES:

SS:	SPACE STATION
SP:	TRANSPORTATION NODE
CLV:	CARGO LAUNCH VEHICLE
SETI:	SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE
RT:	RADIO TELESCOPE

VLFA:	VERY LOW FREQUENCY ARRAY
OPTINTF:	OPTICAL INTERFEROMETER
LBS:	LUNAR BACKSIDE
LS:	LUNAR SURFACE
L1, L2:	EARTH-MOON LIBRATION POINTS
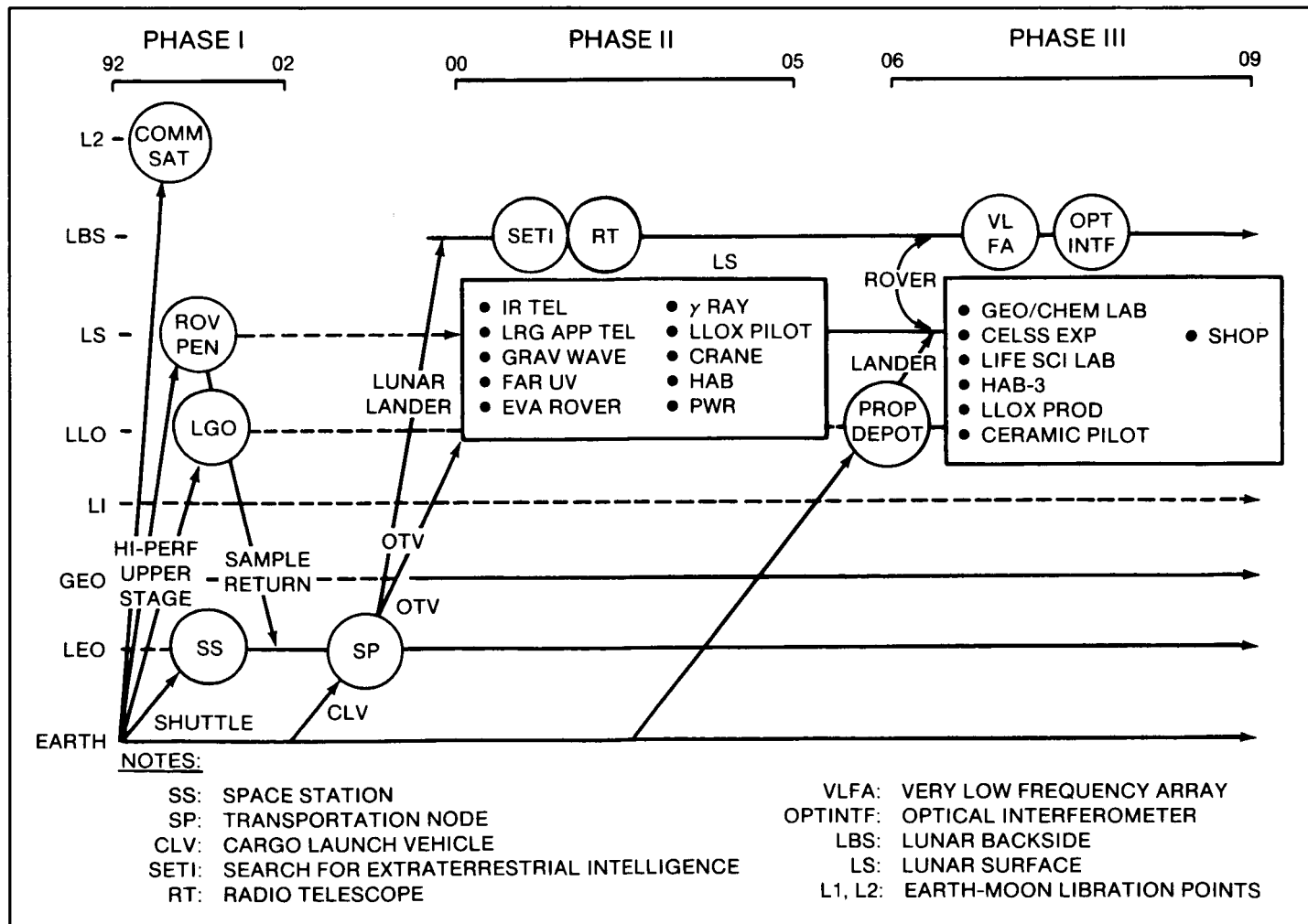
Phase II: 2000 to 2005: Temporarily occupied outpost: Humans in space, promoting emergent, front-line science and research.

In phase II, the capability for temporary habitation at the lunar base is possible. Another discriminator between this phase and the subsequent phases that have permanent habitation capability is that lunar propellants are not utilized in the transportation system. However, the lunar propellant production process is being certified during this phase. The description of the capabilities at this phase are: total Earth dependence; numerous science facilities are available but limited in size; fully closed, regenerative physico-chemical life support systems are available; local personnel surface transportation is available; power capability will range from 0.1 to 1 megawatt; Earth-to-lunar-surface (ETLS) delivery capability equals 20 metric tons; the number of lunar base personnel begins with 0 and grows to 4.

The required supporting systems and infrastructure needed for this phase are: Space Station (with "spaceport" capability near the end of this phase), aerobraking Orbital Transfer Vehicle (OTV) with personnel carrier, lunar lander (a derivative of the OTV), and a cargo ETO vehicle.

Phase III: 2007-2012: Permanently occupied base: Humans in space, operating major science and research facilities and initiating an export economy.

Phase III is the first time that lunar resources are used for internal support to lunar development. Lunar liquid oxygen (LOX) is used to fuel the vehicle that shuttles from the lunar surface to lunar orbit. It is also now possible to permanently reside at the lunar base. The capabilities at this phase are: Lunar LOX (LLOX) is utilized in the near-moon transportation system which halves the Earth support burden, a low Lunar Orbit (LLO) transportation node is installed, major science facilities are operational, long range personnel surface transportation is available, R & D for Controlled Ecology Life Support Systems (CELSS) is under way, R & D is being conducted for ceramic processes that allow "primitive" construction in the next phase, a power capability from 1 to 10 megawatts is available, ETLS delivery capability will equal 40 Metric-tons, and the number of personnel begins at 4 and grows to 30.

The mission analysis task for this phase demonstrates the need (in addition to all of phase II needs) for the fully operational low Earth orbit (LEO) space transportation node and the LLO space transportation node.

Near-Term Decisions

The major near-term decisions that the agency must begin to consider are those that are major new initiatives, new organizational structures, or phase C/D new starts on hardware. The following data presuppose a public mandate for the Lunar Base. The impact is that we can plan on 7 to 8 year development, otherwise, add 2 to 4 years.

Major New Initiatives

- FY 1988: Approve PATHFINDER component of new technology initiative
- FY 1992: Approve PIONEER component of new technology initiative
- FY 1990: Organize the Lunar Base definition team (Program Office in FY 1994)
- FY 1992: Approve new start for both the LEO transportation node and the cargo launch vehicle
- FY 1994: Approve new start for the Lunar Base Program

Index

Index

Reference Number	Significant Task

OSSA 9   **Cell Science Research in Simulated Microgravity**

Funded by: Microgravity (UPN 694)
Principal Investigators: David A. Wolf/SD4, Marian L. Lewis/SD4, Thomas J. Goodwin/SD4
Task Performed by: Johnson Space Center
Krug International Contract NAS9-17720

OSSA 10   **Mode C Preflight Adaptation Trainer**

Funded by: Launch and Mission Support (UPN 560)
Principal Investigators: J. Harris/SD5, D. Parker/SD5, M. Reschke/SD5, D. Aarm/SD5

OSSA 11   **Retinal Fluorescein Angiography During Simulated Extravehicular Activity**

Funded by: Life Sciences (UPN 199)
Technical Monitors: James M. Waligora/SD5 and David J. Horrigan/SD5
Principal Investigators: Richard Meehan/SD4 (UTMB) and James P. Bagian/CB

OSSA 12   **Implementation of the Medical Information Bus (IEE P1073) for the Space Station Health Maintenance Facility**

Funded by: Life Sciences (UPN 199)
Principal Investigator: David V. Ostler/SD12
Task Performed by: Krug International Contract NAS9-17720

OSSA 13   **Zero-G Laryngoscopy and Oral Endotracheal Intubation**

Funded by: Life Sciences (UPN 199)
Principal Investigator: John M. Schultz/SD12
Task Performed by: Krug International Contract NAS9-17720

OSSA 14   **Diagnostic Radiologic Imaging for the Health Maintenance Facility**

Funded by: Life Sciences (UPN 199)
Principal Investigator: Charles E. Willis/SD12
Task Performed by: Krug International Contract NAS9-17720

OSSA 15   **Clinical Chemistry Analyzer for the Space Station Health Maintenance Facility**

Funded by: Life Sciences (UPN 199)
Principal Investigator: Bruce A. McKinley/SD12
Task Performed by: Krug International Contract NAS9-17720

OSSA 16   **Sterile Water for Injection System for the Space Station Health Maintenance Facility**

Funded by: Life Sciences (UPN 199)
Principal Investigators: Bruce A. McKinley/SD12 and John M. Shulz/SD12
Task Performed by: Krug International Contract NAS9-17720

OSSA 17   **Non-Intrusive Data Collection System**

Funded By: Life Sciences (UPN 199)
Principal Investigator: Frances E. Mount/SP3
Task Performed by: Lockheed Engineering and Management Services Co., Contract NAS9-17900

OSSA 18   **Man-Model Development**

Funded by: Life Sciences (UPN 199)
Principal Investigator: Barbara Woolford/SP3
Task Performed by: University of Pennsylvania subcontract to Lockheed Engineering and Management Services Co.

Solar System Exploration

OSSA 19   **Formation of Tonalites by Low Pressure Partial Melting**

Funded by: Planetary Materials (UPN 152)
Principal Investigator: Gary Lofgren/SN4
Task Performed by: Johnson Space Center
Lockheed Engineering and Management Services Co., Contract NAS9-17900

OSSA 20   **Shock Implantation of Gases into Silicate Materials and Implications for Studies of the Martian Atmosphere**

Funded by: Planetary Materials (UPN 152)
Principal Investigators: Donald Bogard/SN4 and Friedrich Hörz/SN4
Task Performed by: Johnson Space Center
Lockheed Engineering and Management Services Co., Contract NAS9-17900

Reference Number	Significant Task

OSSA 21 **Impact Experiments in Reduced-Gravity Environments**

Funded by: Planetary Materials (UPN 152)
Principal Investigators: Mark Cintala/SN4 and Friedrich Hörz/SN4
Task Performed by: Johnson Space Center
　　　　　　　　　　Lockheed Engineering and Management Services Co., NAS9-17900

OSSA 22 **Thermodynamic Properties of Planetary and Spacecraft Materials Measured by Differential Scanning Calorimetry**

Funded by: Planetary Materials (UPN 152)
Principal Investigator: James Gooding/SN2
Task Performed by: Johnson Space Center

OSSA 23 **Hematite on the Surface of Mars**

Funded by: Planetary Materials (UPN 152)
Principal Investigator: Richard V. Morris/SN4
Task Performed by: Johnson Space Center

OSSA 24 **Volcanism and Growth of the Continental Crust**

Funded by: Planetary Materials (UPN 152)
Principal Investigator: Charles A. Wood/SN4
Task Performed by: Johnson Space Center

Office of Aeronautics and Space Technology

OAST 1 **Chemical Heat Pump for Portable Life Support Systems**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: Patricia A. Petete/EC2
Task Performed by: Hydrogen Consultants, Inc. Contract NAS9-17819

OAST 2 **Two Phase Thermal Management System Component Development**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: Richard C. Parish/EC2
Task Performed by: Sundstrand Corporation, Contract NAS9-17195

OAST 3 **Supercritical Water Oxidation of Urine and Feces**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: D. F. Price/EC5
Task Performed by: Modar, Inc., Contract NAS2-12176

OAST 4 **Space Station Materials Evaluation Studies**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: James T. Visentine/ES5
Task Performed by: Los Alamos National Laboratory, Cooperative Agreement 4-199-014

OAST 5 **Testing and Analysis of the Department of Defense Ada Language**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: Stephen A. Gorman/FR12
Task Performed by: University of Houston/Clear Lake, Contract NCC9-16

OAST 6 **Guidance, Navigation, and Control Systems Management and Partioning**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: A. E. Brandli/EH3
Task Performed by: TRW, Inc., Contract NAS9-17716

OAST 7 **Space Station Adaptive Control for Deployment and Operations**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: Lynda R. Bishop/EH2
Task Performed by: C. S. Draper Laboratory, Contract NAS9-17560

OAST 8 **AIPS Hardware for Data Management System Laboratory**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: L. W. McFadin/EH6
Task Performed by: C. S. Draper Laboratory, Contract NAS9-17560

Reference Number	Significant Task

OAST 9   **Crew Station Human Factors: Human-Computer Interaction Laboratory**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: M. Rudisill/SP3
Task Performed by: Lockheed Engineering and Management Services Co., Contract NAS9-17900

OAST 10   **EVA Helmet-Mounted Display**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: B. J. Woolford/SP3
Task Performed by: Johnson Space Center

OAST 11   **Artificial Intelligence—Human Interface with Expert and Planning Systems**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: Jane Malin/EF5
Task Performed by: University of Illinois, Contract NAG9-137
University of Michigan, Contract NAG9-139
Intellicorp, Contract NAS9-17686

OAST 12   **Tailorable Advanced Blanket Insulation**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: R. Richard/EX3
Task Performed by: Rockwell International, Contracts NAS9-14000, NAS9-17244

OAST 13   **Zero-Gravity Gaging for Cryogenic Fluids**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: N. E. Munoz/EP4
Task Performed by: Ball Aerospace Systems Division, Contract NAS9-17378

OAST 14   **Aerothermal Instrumentation Package**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: Robert L. Giesecke/EX3
Task Performed by: Rockwell International, Contract NAS9-14000

OAST 15   **The Orbital Research Experiment**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: M. K. Hendrix/EX3
Task Performed by: KMS Fusion, Contract NAS9-17348

OAST 16   **AEF Aerodynamics/Aerothermodynamics/Computational Fluid Dynamics**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitors: C. Cerimele, J. Gamble, R. Gomez, M. Jansen, C. Li, C. Scott/ED
Task Performed by: Lockheed Engineering and Management Services Co., Contract NAS9-17900

OAST 17   **System Control Module**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: R. M. Giesecke/EX3
Task Performed by: Lockheed Engineering and Management Services Co., Contract NAS9-17900

OAST 18   **Transportation Technologies Required for New Space Initiatives**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: C. J. Mallini/ED2
Task Performed by: Lockheed Engineering and Management Services Co., Contract NAS9-17900

OAST 19   **Design Goals and Technology Requirements for Future Launch Systems**

Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: A. J. Petro/ED2
Task Performed by: Lockheed Engineering and Management Services Co., Contract NAS9-17900

Office of Space Flight

OSF 1   **Environmental Control and Life Support Technology Study for Advanced Manned Missions**

Funded by: Advanced Development (UPN 906)
Principal Investigators: Chin H. Lin/EC2 and Melanie M. Sedej/EC2
Task Performed by: Life Systems, Inc., Contract NAS9-17531

Reference Number	Significant Task

OSF 2   **Advanced Extravehicular Activity Systems Requirements Definition Studies**

Funded by: Advanced Development (UPN 906)
Principal Investigator: Terry O. Tri/EC3
Task Performed by: Essex Corporation, Contract NAS9-17779
           Arthur D. Little, Contract NAS9-17894

OSF 3   **Advanced Extravehicular Activity Glove Development**

Funded by: Advanced Development (UPN 906)
Principal Investigator: Joseph J. Kosmo/EC3
Task Performed by: David Clark Co., Contract NAS9-16347
           ILC/Dover, Contract NAS9-17447

OSF 4   **Launch Vehicle Synthesis and Program Enhancements**

Funded by: Advanced Development (UPN 906)
Principal Investigator: Charles J. Mallini/ED2
Task Performed by: Johnson Space Center
           Lockheed Engineering and Management Services Co., NAS9-17900

OSF 5   **Space-Shuttle-Derived High-Altitude Atmospheric Density Model**

Funded by: Advanced Development (UPN 906)
Technical Monitor: Joe D. Gamble/ED3
Task Performed by: Flight Mechanics and Control, Inc., Contract NAS9-17394

OSF 6   **Orbital Debris**

Funded by: Advanced Development (UPN 906)
Principal Investigators: Donald J. Kessler/SN3, Andrew E. Potter/SN3, Eugene G. Stansberry/SN3
Task Performed by: Lockheed Engineering and Management Services Co., Contract NAS9-17900

OSF 7   **Satellite Services System**

Funded by: Advanced Development (UPN 906)
Technical Monitor: Gordon Rysavy/EX2
Task Performed by: Lockheed Engineering and Management Services Co., Contract NAS9-17900

OSF 8   **Interactive Control System Design**

Funded by: Advanced Development (UPN 906)
Technical Monitors: Edward T. Kubiak/EH2 and Duane A. Johnson/EH2
Task Performed by: Lockheed Engineering and Management Services Co., Contract NAS9-17900

OSF 9   **Robotic Vision Tracking Sensors**

Funded by: Advanced Development (UPN 906)
Technical Monitor: James C. Lamoreux/EE6
Task Performed by: Lockheed Engineering and Management Service Co., Contract NAS9-17900
           McDonnell Douglas Technical Services Co., Contract NAS9-16715

OSF 10   **Data and Software Systems Commonality**

Funded by: Advanced Development (UPN 906)
Principal Investigator: Robert G. Musgrove/EH6
Task Performed by: TRW Inc., Contract NAS9-17554

OSF 11   **Automated Software Development Workstation**

Funded by: Advanced Development (UPN 906)
Principal Investigator: Robert N. Hinson/FM7
Task Performed by: Inference Corp., Contract NAS9-17766

OSF 12   **Development of Advanced Graphics Lab Applications**

Funded by: Advanced Development (UPN 906)
Principal Investigator: Gunter Sabionski/FM7
Task Performed by: Lincom Corp., Contract NAS9-17606

OSF 13   **Advanced Space Flight Simulation Technology**

Funded by: Advanced Development (UPN 906)
Principal Investigator: H. K. Hiers/EF5
Task Performed by: Lockheed Engineering and Management Services Co., Contract NAS9-17900

Reference Number	Significant Task

OSF 14   **Optical Communication Systems**

Funded by: Advanced Development (UPN 906)
Principal Investigator: Joseph L. Prather/EE6
Task Performed by: Johnson Space Center
Lockheed Engineering and Management Services Co., Contract NAS9-17900
McDonnell Douglas Technical Services Co., Contract NAS9-17650
Wilton Industries

OSF 15   **Ada-ART: Specifications for and Ada-based State-of-the-Art Expert System Construction Capability**

Funded by: Advanced Development (UPN 906)
Principal Investigator: Robert T. Savely/FM7
Task Performed by: University of Houston, Clear Lake, Contract NCC9-16
Inference Corp.

OSF 16   **Advanced Mission Cost Model**

Funded by: Advanced Development (UPN 906)
Principal Investigator: Kelly Cyr/BX24
Task Performed by: Johnson Space Center

OSF 17   **Autonomous Ascent Guidance Development**

Funded by: Advanced Development (UPN 906)
Technical Monitor: A. Bordano/FM4
Task Performed by: Johnson Space Center
McDonnell Douglas Technical Services Co., Contract NAS9-17650

OSF 18   **Strategic Planning for a Lunar Base**

Funded by: Advanced Development (UPN 906)
Technical Monitor: Barney B. Roberts/ED1
Task Performed by: Batelle Columbus Labs, Contract NAS9-17356
Arthur D. Little Inc., Contract NAS9-17335

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15. Supplementary Notes

16. Abstract

Johnson Space Center accomplishments in new and advanced concepts during 1987 are highlighted. Included are research projects funded by the Office of Aeronautics and Space Technology, Solar System Exploration and Life Sciences research funded by the Office of Space Sciences and Applications, and Advanced Programs tasks funded by the Office of Space Flight. Summary sections describing the role of the Johnson Space Center in each program are followed by descriptions of significant projects. Descriptions are suitable for external consumption, free of technical jargon, and illustrated to increase ease of comprehension.

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C-2